TEEB FOR AGRICULTURE & FOOD

SCIENTIFIC AND ECONOMIC FOUNDATIONS REPORT

The Economics of Ecosystems & Biodiversity

‘The Economics of Ecosystems and Biodiversity’ (TEEB) is an initiative hosted by United Nations Environment Programme (UN Environment), and coordinated by the TEEB Office in Geneva, Switzerland. ‘TEEB for Agriculture & Food’ (TEEBAgriFood) encompasses various research and capacity-building projects under TEEB focusing on the holistic evaluation of agriculture and food systems along their value chains and including their most significant externalities. This ‘Scientific and Economic Foundations’ report addresses the core theoretical issues and controversies underpinning the evaluation of the nexus between the agri-food sector, biodiversity and ecosystem services and externalities including human health impacts from agriculture on a global scale. It is supported by the Global Alliance for the Future of Food.

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TEEB FOR AGRICULTURE & FOOD
SCIENTIFIC AND ECONOMIC FOUNDATIONS REPORT

TABLE OF CONTENTS

Page

CHAPTER 1

TEEB for Agriculture & Food: background and objectives

Chapter 1 introduces 'The Economics of Ecosystems and Biodiversity for Agriculture and Food' (TEEBAgriFood) and its mission statement, within the context of the wider TEEB initiative. It highlights the need to fix food metrics by applying a holistic systems approach and evaluating the impacts and dependencies between natural systems, human systems and agriculture and food systems. Further, it explores the rationale and objectives of the Scientific and Economic Foundations report based on the extent of positive and negative externalities in 'eco-agri-food systems' and the lack of a coherent, universal framework, thus setting up the narrative and outline for the rest of the report.

Page

CHAPTER 2

Systems thinking: an approach for understanding 'eco-agri-food systems'

Chapter 2 makes the case for using systems thinking as a guiding perspective for TEEBAgriFood's development of a comprehensive Evaluation Framework for the eco-agri-food system. Many dimensions of the eco-agri-food system create complex analytical and policy challenges. Systems thinking allows better understanding and forecasting the outcomes of policy decisions by illuminating how the components of a system are interconnected with one another and how the drivers of change are determined and impacted by feedback loops, delays and non-linear relationships. To establish the building blocks of a theory of change, systems thinking empowers us to move beyond technical analysis and decision-tool toward more integrated approaches that can aid in the forming of a common ground for cultural changes.

Page

CHAPTER 3

'Eco-agri-food systems': today's realities and tomorrow's challenges

Chapter 3 provides an overview of the diversity of agriculture and food systems, each with different contributions to global food security, impacts on the natural resource base and ways of working through food system supply chains. We describe "eco-agri-food systems" and further identify their many manifestations through a review of typologies. We identify challenges ahead with existing systems due to prevailing economic and political pressures resulting in patterns of invisible flows and impacts across global food systems. We describe pathways to ensure sustainability by securing the benefits from working with, rather than against, natural systems and ecosystem processes and the challenges for farmers, communities and societies to reorient food value chains and build resilience in eco-agri-food systems.

Page

CHAPTER 4

Human health, diets and nutrition: missing links in eco-agri-food systems

Chapter 4 outlines ways in which the food system impacts human health - directly or indirectly, negatively or positively – as well as food and nutritional security. It is illustrated how human health is compromised throughout our current food system both for end-point consumers and for those working along the supply chain. This chapter explores a number of endpoints in various food system strategies and creates a context for exploration, mitigation, change, and ultimately transformation of our global food system to one in which health – of humans, ecosystems, and communities – is the norm. We also illustrate ways in which various trends (e.g. climate change, fresh water, demographic shifts) alter the challenge of improving human health via food system activities.

Page

CHAPTER 5

Social equity, ethics and justice: missing links in eco-agri-food systems

Chapter 5 explores the impact of food systems on key aspects of social equity and justice, addressing particular ethical considerations related to hunger, sustainability, human rights, safety, marketing, trade, corporations, diets and animal welfare among others. The chapter identifies key components of food systems to promote equity from production to consumption, to food waste management. In an equitable food system, everyone has access to healthy food and the benefits and burdens of the food system are equitably distributed. These require policies that ensure poor people's access to land, natural resources, technologies, markets, rights and gender equality. The chapter concludes that social equity, justice and ethical considerations should be fundamental values of our food system and the Sustainable Development Goals (SDGs).

Page

CHAPTER 6

The TEEBAgriFood Framework: towards comprehensive evaluation of eco-agri-food systems

Chapter 6 presents the TEEBAgriFood Evaluation Framework. The Framework establishes "what should be evaluated" and represents the next generation in assessment tools for eco-agri-food systems. It supports the assessment of different eco-agri-food systems, covering their human, social, economic, and environmental dimensions, from production through to consumption. The common, production-only, focus of assessment, using for example metrics of yield per hectare, ignores the significant range of social and environmental impacts that must be included for a complete evaluation. The Framework applies a multiple-capitals based approach, and supports the use of monetary and non-monetary approaches to impact assessment, including value-addition. As a comprehensive and universal framework, it highlights all relevant dimensions, and drives policymakers, researchers, and businesses to broaden their information set for decision-making.

Page

CHAPTER 7

TEEBAgriFood methodology: an overview of evaluation and valuation methods and tools

Chapter 7 presents an overview of available evaluation and valuation methods and tools relevant to the analysis of dependence and impacts of various agricultural and food systems on human wellbeing. The market and non-market valuation tools and methods address to varying degrees the positive and negative externalities along the value chain of eco-agri-food systems. However, challenges emerge from the complexity of the systems, stemming from the temporal and spatial dimensions and management practices and value attribution across multiple ecosystem services. As decision making requires integration of economic values with other social and economic dimensions, the chapter presents an integrated systems approach, which helps in incorporating various dimensions together to evaluate the impact of various policies on the human wellbeing.

Page

CHAPTER 8

Application of the TEEBAgriFood Framework: case studies for decision-makers

Chapter 8 demonstrates an initial exploration of the TEEBAgriFood Evaluation Framework through ten existing case studies that focus on various aspects of the value chain: agricultural management systems, business analysis, dietary comparison, policy evaluation and national accounts for the agriculture and food sector. Various issues within the Framework are explored, including the need for future modifications and adaptations. The case studies have helped identify opportunities to both expand particular aspects of the Framework for comparisons as well as to introduce spatial and temporal contexts. The explorations within this chapter are an introduction to a process that will continue to expand, as lessons are learned with each application of the Framework.

Page

CHAPTER 9

The TEEBAgriFood theory of change: from information to action

Chapter 9 shows how adopting the TEEBAgriFood Evaluation Framework can bridge the gap between knowledge and action. Factors that block the absorption of externalities in food systems, including path dependency and counter-narratives regarding healthy diets, lead us to derive lessons for transformational change reflecting the critical role of power relations. Experience in agri-food certification and multi-stakeholder roundtables bespeak the need to address change from the starting point of key actors and relevant groups, including farmers, government, industry and consumers. Successful change in food systems to reflect invisible values can be enabled by identifying specific action roles through partnerships and alliances as well as multilateral agreements including the SDGs.

Page

CHAPTER 10

TEEBAgriFood and the sustainability landscape: linking to the SDGs and other engagement strategies

Chapter 10 applies TEEBAgriFood's Theory of Change to develop specific engagement strategies for TEEBAgriFood. Transformations of the eco-agri-food system depend on alliances for change. Therefore, the chapter situates TEEBAgriFood in the normative framework provided by the Right to Food and relates it to other valuation initiatives. The chapter emphasizes TEEBAgriFood's contribution to the integrated implementation of the 2030 Agenda. By identifying and mapping the positive and negative externalities of specific eco-agri-food system measures, TEEBAgriFood identifies synergies and trade-offs between the SDGs. Proceeding like this, TEEBAgriFood supports follow up and review of the 2030 Agenda. Overall, the chapter emphasizes the benefits from a strategic application of TEEBAgriFood insights for eco-agri-food system transformation.

FOREWORD

2,500 years ago Socrates established *“the importance of seeking evidence, closely examining reasoning and assumptions, analyzing basic concepts, and tracing out implications not only of what is said but of what is done as well.”*[1]

There are two important elements here. The first is establishing “the importance of seeking evidence, closely examining reasoning and assumptions, analyzing basic concepts.” As we wrestle with how to boldly meet the scale and complexity of the challenges we face as a global community – climate change, skyrocketing rates of diabetes and obesity, biodiversity loss, migration, deepening poverty and hunger – we can’t underestimate the need to find transformative solutions; the need for tools that help us seek evidence, examine long-held assumptions, and analyze basic concepts such as transparency, fairness, and accountability.

There is perhaps no other field for which this kind of urgent solution-seeking is needed, as much as food systems. Food systems are one of the most defining issues of our time, at the centre of many of the critical issues we face today, with their impacts experienced unequally across the globe and the burden placed on vulnerable and marginalized populations. Thus, getting the future of food right, quickly, is fundamental to fulfilling our daunting commitments to the Sustainable Development Goals, Paris Agreement, and other indispensible international treaties and conventions.

This is why what follows in this report is so timely, imperative, and potentially transformative. The TEEBAgriFood Framework is arguably one of the most important tools we now have in our food systems toolbox to understand, analyze, and shift food systems through its ability to highlight what’s wrong with the current system and point to changes needed to bring about a more desirable future, while leaving no one behind.

Which brings us to the second element of Socrates’ efforts: establishing *“the importance of tracing out implications not only of what is said but of what is done as well.”* Evidence and analysis for evidence-and-analysis-sake is, of course, not enough in this time of urgency and global consequence. Socrates’ emphasis was on the *“implications for what is done.”* In other words, to imply action.

The ultimate goal of TEEBAgriFood is action. It is food systems’ transformation towards – in the words of the TEEBAgriFood leadership – *“sustainable agrifood systems that nourish, provide energy, damage neither health nor environment, and support equitable access to resources.”* It is getting the future of food right, one that will lead us along a path to real sustainability, along which we can draw ever closer to ending poverty, protecting the planet, and ensuring prosperity for all.

We at the Global Alliance for the Future of Food are behind this agenda. We are committed to food system reform and believe that transformational change at the scale and speed needed requires us to see the whole system in necessary and powerful new ways. And to make choices about the future of our shared food systems; choices that avoid siloed approaches, unintended consequences, and limited, narrow, short-term solutions.

But it’s an agenda for all of us. We are all part of the food system. For current and future generations, this is a shared responsibility upon which we, as a global community, simply must act to better understand the impacts of food

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[1] Foundation for Critical Thinking, 2016, p.1

systems, address the most harmful practices, and find new positive pathways forward, together. TEEBAgriFood now gives us a potent means by which to do that.

It is our hope, through collective effort and broad-based support, that TEEBAgriFood will realize its potential as a formidable tool for change in our urgent pursuit of food systems that are truly sustainable, secure, and equitable.

Sincerely,

Ruth Richardson
Executive Director
Global Alliance for the Future of Food

FOREWORD

The world's food systems face two immense challenges today. One, to produce enough food to nourish a global population of seven billion people without harming the environment. Two, to make sure food systems deliver nutrition to everyone, particularly the world's poorest, many of whom suffer from chronic under-nutrition. This Report produced by The Economics of Ecosystems and Biodiversity for Agriculture and Food Scientific Foundation, aims to support the design of sustainable and equitable food systems for the future.

The way we are currently producing food is negatively impacting climate, water, top soil, biodiversity and marine environments. If we do not change course, we will seriously undermine our ability to deliver adequate food for future populations. In addition to the negative environmental impacts, we are struggling to deliver nutritious and healthy diets in an equitable way. Diet-related chronic diseases are on the rise even as we fail to deliver nutritious food to millions of poor people around the world.

As I write, a remarkable change is underway in the West Godavari district of Andhra Pradesh in India. Thousands of farmers are now turning to zero budget natural farming, replacing chemical fertilizers and pesticides with natural inputs. Its rejuvenating soil, delivering higher yields and improving biodiversity. UN Environment is proud to be partnering now with the Government of Andhra Pradesh and private sector partners to provide private capital to scale-up this initiative to six million farmers in the state.

The global development agenda aims to "leave no one behind". Re-designing food systems that do no harm to the environment, improve nutrition for all, and ensure decent work, is at the heart of this agenda. This Report authored by experts from around the world, provides a clear set of recommendations on designing and evaluating food systems for their impact on nature and human health. I hope that it provides useful insights to national planners, farmers and agriculturists, and citizens, thereby strengthening the links between health, prosperity and our planet.

Erik Solheim

Erik Solheim
Executive Director
UN Environment

PREFACE

In 2015, UN Member States endorsed two global agreements: the 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change. Both agreements are highly ambitious and require far-reaching commitments and action from all countries of the world for their successful implementation.

The 2030 Agenda for Sustainable Development, with its 17 Sustainable Development Goals (SDGs), states that:

> *"All countries and all stakeholders, acting in collaborative partnership, will implement this plan. We are resolved to free the human race from the tyranny of poverty and want and to heal and secure our planet. We are determined to take the bold and transformative steps which are urgently needed to shift the world on to a sustainable and resilient path. As we embark on this collective journey, we pledge that no one will be left behind"* (UN 2015).

The Paris Agreement on Climate Change sets out a global action plan to limit global temperature increase to well below 2 degrees centigrade. Having agreed upon actions necessary to mitigate climate change and to adapt to changing climatic conditions, the Paris Agreement also refers to necessary financial support to developing countries and for technology transfer.

Both agreements have very often been characterized as a global plan of action for "people, planet and prosperity". One thing is clear: the main messages coming out of the 2030 Agenda and the Paris Agreement is that business as usual is not an option! Therefore, clear strategies for transformative action towards sustainability are needed; these agreements now require implementation at all levels.

When it comes to their implementation at both global and national levels, energy and food are often identified as the two most important issues which are crucial for the success or failure of these two agreements. Without transforming the way we produce energy, and the way we produce and consume food, these international agendas will not be achieved. Energy and food are not only fundamental for the everyday life of every single person, they also have far reaching impacts on the human, social and environmental fabric of our planet.

Regarding the future of global energy systems, a consensus is emerging that renewable energies will play a decisive role in supplying sustainable energy. There are a range of issues related to this, including complex technical questions, financing for investments, the vested interests of coal, oil and gas companies, countries with high revenues from fossil fuels which face the problem of how to generate alternative income, employment and social stability, and also issues of a geopolitical nature. Nevertheless, it is clear that emissions from burning fossil fuels have to be cut drastically and that renewable energy sources are a key to a sustainable future.

Food, however, is a much more complex arena. For example, there are many different production systems, food is produced over a broad range of agroecological zones, and the cultural heritage and value of agriculture and food systems should not be underestimated. Agriculture is by far the largest employer in the world, employing around 1.5 billion people, including landless workers, farmers (small and big), family members and (legal and illegal) migrants working to produce food. In contrast to this huge number of people earning their living through agriculture, the globalization and concentration of multinational food business has reached an all-time high; multi-billion-dollar mergers are happening and input-providers (e.g. agricultural chemicals, seeds) are becoming a dominant global power.

The impact of today's agriculture and food systems on natural resources is enormous: globally, agriculture is responsible for using 70 per cent of all freshwater withdrawn from the natural cycle, for causing 60 per cent of all biodiversity loss, and for creating large-scale land degradation. On the other hand, the world of today is producing more food than ever, and enough calories to feed all people. Despite this, over 800 million are hungry and food-related lifestyle diseases such as obesity and diabetes are on the rise. At the same time, one-third of all agricultural produce, around 1.3 billion tons every year, ends up as food waste or loss. The SDGs will not be achieved without a transformation of the way we are producing, processing, distributing and consuming food.

Humankind nourished itself for two and a half million years by hunting wild animals and gathering plants they could find in the environment. This changed only around 10,000 years ago as we concentrated all of our efforts on - as Yuval Noah Harari (2014) put it - "manipulation" of some animal and plant species. This "agricultural revolution" changed the everyday life of some and eventually all people; finally, agriculture has fundamentally altered the face of the earth. Population growth as we know it today, division of labor, development of all kinds of technologies and urbanization, would not have been possible without the agricultural revolution.

This agricultural revolution is still very strongly influencing our food production. Today we are producing 90 per cent of all calories from a handful of plant species based on the domestication initiated successfully by our ancestors between the years 9,500 and 3,500 BC. 10,000 years ago, only a few million sheep, cows, goats and chicken were living on the planet; today the estimate is that a billion sheep, more than a billion cows and around 25 billion chickens are reared to produce protein for more than 7.5 billion people. In the last two thousand years, no important (in terms of calories) plant or animal species have been added to our food basket (Harari 2014).[1]

Producing crops and animals to feed a growing population had and still has a huge impact on our planet. In their book "Big World, Small Planet", Rockström and Klum (2015) identified areas where activities of humankind have already transgressed what is considered a 'safe operating space' for humanity – the biophysical state which so far has supported our modern life. Emissions of CO2, biodiversity loss, nitrogen and phosphorus overload are the first areas where we are transgressing planetary boundaries. One cannot deny it: food production is one of the most important drivers of change on our planet.

The task for agriculture and food systems in the years to come is huge: feeding a population projected to reach 10 billion in 2050, achieving the four dimensions of food security (FAO 1996) for all people by providing healthy food, drastically reducing the impacts of different types of agricultural production on the world's ecosystems, reducing greenhouse gas emissions to limit climate change and to adapt to it, developing rural areas to create jobs and to improve livelihoods of poor people, maintaining ecosystem services such as clean water and air for a rapidly urbanizing planet are only some of the challenges.

Tackling these challenges requires a systematic approach. So far food production has successfully been increased, but the environmental impacts have received a lot less attention. They have been either ignored or been considered as a necessary trade-off. A comprehensive analysis of the whole eco-agri-food system including social equity and jobs as well as health and environmental impacts has not been developed.

We consider TEEBAgriFood an important contribution to the transformation of agriculture and food systems. In this report, you will find the collective legacy of our broad and diverse community of experts: a systems approach for bringing together the various disciplines and perspectives related to agriculture and food, a framework for evaluation that supports the comprehensive, universal and inclusive assessment of eco-agri-food systems, a set of methodologies and tools for the measurement of positive and negative externalities, and a theory of change to help integrate TEEBAgriFood into the wide landscape of platforms and initiatives, like the SDGs, that are tackling these complex issues.

Only on the basis of such a complex and comprehensive analysis can a transformation towards sustainable food systems take place. We will have to radically reduce the

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[1] Interestingly Harari unfolds his thesis that it is the plants (wheat, rice, potatoes, etc.) that have domesticated humankind, and not the other way round!

harmful environmental impacts of food systems while seeking to produce healthier and more accessible food, simultaneously improving the livelihoods and security of vulnerable people and maintaining life-supporting services for humankind.

This report marks the beginning of many things: of an analysis to inform researchers, civil society, businesses, policymakers, farmers and consumers, of a new and unique approach for evaluating agriculture and food systems, of an emerging community of practice dedicated to uncovering the hidden costs and benefits, i.e. the negative as well as the positive externalities of agriculture and food, and, importantly, of the timely opportunity for us to work collaboratively toward a shared set of goals and ambitions for future generations.

As Study Leader of this initiative, I want to thank all my colleagues (close to 150 from over 30 countries) having worked very hard in the last months to contribute to this report, the TEEB Office in UN Environment, and especially the Special Advisor Pavan Sukhdev, whose experience with successfully pioneering the TEEB approach was key for this report.

Now I hope that you, the reader, will get new ideas and inspiration on how to achieve really sustainable food systems to feed a world with 10 billion people. We need to build an alliance to leave no one behind and sustainable eco-agri-food systems are a very important building block!

Signed,

Alexander Müller
Study Leader, TEEBAgriFood
Chair, TEEBAgriFood Steering Committee
Managing Director, TMG – Thinktank for Sustainability

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LEXICON

agri-food (as in system): a subset of *eco-agri-food* in which ecological considerations (e.g. impacts and dependencies upon *natural capital*) are often left out

capital: the economic framing of the various stocks in which each type of capital embodies future streams of benefits that contribute to human well-being (see also '*stock*' as well as '*human capital*', '*natural capital*', '*produced capital*' and '*social capital*')

consumption: the final of four stages in the value chain, including purchases of food for consumption within the household, purchases of food supplied by restaurants and the hospitality industry more generally, and consumption of food grown at home

distribution, marketing and retail: the third of four stages in the value chain, including the activities associated with the transport and sale of goods, for example to retailers or consumers

driver: a *flow* which arises from the activities of agents (i.e. governments, corporations, individuals) in eco-agri-food value chains, resulting in significant *outcomes* and leading to material *impacts*

eco-agri-food (as in system): a descriptive term for the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labor, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food

ecosystem service: the contributions that ecosystems make to human well-being (e.g. classified by CICES into provisioning, regulation & maintenance and cultural)

externality: a positive or negative consequence of an economic activity or transaction that affects other parties without this being reflected in the ~~cost~~ price of the goods or services transacted

feedback (loop): a process whereby an initial cause ripples through a chain of causation, ultimately to re-affect itself

flow: a cost or benefit derived from the use of various capital stocks (categorized into agricultural and food outputs, purchased inputs, ecosystem services and residuals)

Framework, TEEBAgriFood Evaluation: an approach for describing and classifying the range of outcomes/impacts for a given scope and value chain boundary, and caused by specified drivers, that answers the question "what should be evaluated?"

human capital: the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being

impact: a positive or negative contribution to one or more dimensions (environmental, economic, health or social) of human well-being

manufacturing and processing: the second of four stages in the value chain, including the operations involved in converting raw materials into finished products

marketing: (see '*distribution, marketing and retail*')

natural capital: the limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services.

outcome: a change in the extent or condition of the stocks of capital (natural, produced, social and human) due to value-chain activities

processing: (see '*manufacturing and processing*')

produced capital: all manufactured capital, such as buildings, factories, machinery, physical infrastructure (roads, water systems), as well as all financial capital and intellectual capital (technology, software, patents, brands, etc.)

production: the first of four stages in the value chain, including activities and processes occurring within farm gate boundaries (including the supply of ecosystem services, the supply of goods and services, and connections between producers)

retail: (see '*distribution, marketing and retail*')

social capital: encompasses networks, including institutions, together with shared norms, values and understandings that facilitate cooperation within or among groups

stock: the physical or observable quantities and qualities that underpin various flows within the system, classified as being produced, natural, human or social (see also '*capital*')

system: a set of elements or components that work together and interact as a whole

systems thinking: an approach that focuses on the identification of interrelationships between components of a system

theory of change: a basis for planning intervention in a given policy or project arena that helps to identify processes and preconditions whereby actions can best attain their intended consequences

value: the worth of a good or service as determined by people's preferences and the tradeoffs they choose to make given their scarce resources, or the value the market places on an item

value chain: the full range of processes and activities that characterize the lifecycle of a product from *production*, to *manufacturing and processing*, to *distribution, marketing and retail*, and finally to *consumption* (including waste and disposal across all stages)

CHAPTER 1

TEEB FOR AGRICULTURE & FOOD: BACKGROUND AND OBJECTIVES

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SUMMARY

Chapter 1 introduces 'The Economics of Ecosystems and Biodiversity for Agriculture and Food' (TEEBAgriFood) and its mission statement, within the context of the wider TEEB initiative. It highlights the need to fix food metrics by applying a holistic systems approach and evaluating the impacts and dependencies between natural systems, human systems and agriculture and food systems. Further, it explores the rationale and objectives of the Scientific and Economic Foundations report based on the extent of positive and negative externalities in 'eco-agri-food systems' and the lack of a coherent, universal framework, thus setting up the narrative and outline for the rest of the report.

CONTENTS

FIGURES, BOXES AND TABLES

CHAPTER 1

1.0 KEY MESSAGES

- Chapter 1 sets the scene for the *Foundations* report, i.e. why we need a project on The Economics of Ecosystems and Biodiversity for Agriculture and Food ('TEEBAgriFood'), and specifically why we need a report on *Scientific and Economic Foundations*, and how this report interfaces with the wider TEEB Initiative.

- A short answer is that we need to fix food metrics, and we need to start this by interrogating evidence from the science and economics literatures.

- The longer answer – and the mission statement of TEEBAgriFood – is as follows: The TEEBAgriFood study is designed to (1) provide a comprehensive economic evaluation of the eco-agri-food systems complex, and (2) demonstrate that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive, and a lack of awareness of dependency on natural, social, human and produced capitals.

- The 'eco-agri-food systems complex' is a collective term encompassing the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.

- TEEBAgriFood adopts a systems approach: It is neither possible nor sensible to isolate impacts and dependencies of primary agricultural production (within the farm gate) from the rest of the eco-agri-food system if we are to find truly sustainable and equitable solutions to the agri-food challenges we face.

- Chapter 1 sets out the structure of the report, with four chapter clusters: (i) outlining the systems approach; (ii) evidence that a change in metrics is required (from agriculture, human health, and ethics perspectives); (iii) defining and setting out examples of how we change metrics via the TEEBAgriFood Evaluation Framework; and (iv) how change might be brought about – the Theory of Change.

- The TEEB initiative is ideally situated to operationalize the Theory of Change as it has, for a decade, focused on the economic invisibility of the costs of biodiversity loss and the degradation of ecosystems, and no industrial sector is more reliant on well-functioning ecosystems than the agriculture sector.

- TEEB has championed valuation in its widest form, and thus has eschewed and criticized the commoditization of nature. It has also successfully led to values being recognized, demonstrated and captured in a range of decision-making contexts – for national and sub-national government, for businesses and for consumers and citizens.

CHAPTER 1

TEEB FOR AGRICULTURE & FOOD: BACKGROUND AND OBJECTIVES

1.1 TEEB: GENESIS, SCOPE, ACHIEVEMENTS & EVOLUTION

Across the world, we are building a better understanding of the ramifications of environmental change on human livelihoods. Much of this awareness has been gained after tipping points have been reached or as a result of catastrophic events such as flooding, drought, fire and famine. 'The Economics of Ecosystems and Biodiversity' (TEEB) was originally created to help answer the call to make the values of nature more visible so that decision-making and policy outcomes can be informed by a better understanding of our impacts and dependence on the natural world.

As the world's population grows, so does the need for more resilient food and agricultural systems that address human need while minimizing environmental damage and further biodiversity loss. TEEB is focused on how we can make the values of nature visible to support a transition to agriculture systems that are truly sustainable and benefit both human and environmental health.

1.1.1 Brief History of TEEB

Inspired by the Stern Review on the Economics of Climate Change (Stern 2007), which revealed the economic inconsistency of inaction with regard to climate change, Environment Ministers from the governments of the G8+5 countries[1] agreed at a meeting in Potsdam, Germany in 2007 to "initiate the process of analysing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation". Aiming to address the economic invisibility of nature, TEEB emerged from that decision.

Although the underlying problem of the economic invisibility of environmental damage in decisions is similar to the problem of economic invisibility where loss of biodiversity is concerned, the solutions are very different. To avoid catastrophic climate change, the world needed, and still needs, to reduce greenhouse gas emissions; the task is massive but progress can be charted through the single, universal metric of carbon dioxide equivalence. Where in the world carbon savings are made is important in terms of equity, but in the end it is global emissions measured in carbon dioxide equivalents that matter.

Biodiversity is very different from this perspective in that it is the living fabric of our planet including all its ecosystems, species and genes, in all their quantity and diversity. It is therefore neither intellectually nor ethically appropriate to attempt to reduce this complexity to any single indicator or numeraire. Ethics, social context, ecology and geography matter to both the costs and benefits of action – in other words, people and places are intrinsically important in the context of TEEB. The costs and benefits are also more diverse, from the protection and preservation of water flows through to the pollination of crops as well as links to cultural identity. There is no single target or metric, but multiple benefits which all need to be considered. Combined, these factors implied that, as well as the need to have a global analysis as per the Stern Review, TEEB would only be relevant if it also targeted decisions and decision-makers more directly at the scales and in the contexts in which they were operating.

Furthermore, TEEB also differs from the Stern Review (and the wider climate change discourse) in that the effects of climate change on nature and on human livelihoods are real and potentially catastrophic but do not emerge from within. TEEB is concerned with the why and the how of valuing nature in and of itself, and understanding the incentives for action (and inaction) in many different contexts by a whole range of decision-makers: policy makers at national and local levels, communities, businesses, and society at large. As such, it is also about valuing something that we all cherish, and on which all of our lives depend. This has also meant that TEEB has, since its inception, distanced

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[1] The G8+5 includes the heads of government from the G8 nations (Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States), plus the heads of government of five emerging economies (Brazil, China, India, Mexico and South Africa).

itself from any calls to commoditize nature: *our living planet is most definitely not for sale.* TEEB is concerned with valuing nature's contribution to people, in all its disparate forms.

With this focus in mind, TEEB aims to provide a bridge of valuation knowledge and expertise between the multi-disciplinary science of biodiversity and ecosystem management and the interconnected arenas of policymaking in the international, national and local government domains as well as in business management. In this context, the original phase of the project (2007-2011) developed outputs specifically for these audiences as well as web-based material aimed more directly at citizens and consumers.

The TEEB Synthesis Report (TEEB 2010) collected this work from the original phase where it was presented at the Convention on Biological Diversity's Conference of the Parties in Nagoya, Japan in 2010. The influence of the TEEB studies (and the process of bringing authors and stakeholders together to produce them) was visible both in the decisions made in Nagoya and the work which followed. TEEB was officially welcomed by the Parties in the context of the new Strategic Plan for Biodiversity 2011-2020, as well as featuring explicitly in decision text around incentive measures and business engagement. It is notable that of the 20 international biodiversity targets for 2020 agreed at the meeting (the Aichi Biodiversity targets), target 2 aimed to address the underlying drivers of biodiversity loss requiring that "*by 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.*"

The TEEB initiative was originally scheduled to conclude with the Synthesis Report in 2010, however, the decisions of the 193 countries represented in Nagoya reflected both the need and desire for countries both to deepen their understanding of the connections between nature and the wellbeing of their people, and to ensure these connections are captured. Several countries announced their intention to carry out TEEB country studies and their interest in implementing TEEB recommendations. TEEB revealed that the drivers of biodiversity loss were widespread throughout our economies and societies, and the benefits of addressing these drivers went far beyond biodiversity alone, to include human health and livelihoods, water use and climate stability. TEEB stimulated demand to re-orientate our economic compass, and therefore officially entered an implementation phase of work aimed to put theory and into practice across a range of different areas. This included encouraging the world of business[2] to co-create and publish formal and universal guidance on measuring, valuing and reporting corporate impacts and dependencies on nature (TEEB 2012; Natural Capital Coalition 2016).

TEEB's initial phase catalysed activities to make the impacts and dependencies of societies and public/private interests more visible in order to contribute to better policy and decision-making outcomes, at a number of levels:

- **National** - countries started conducting baseline ecosystem assessments to include Natural Capital in their national accounts; *Local and regional* – ICLEI, an international organisation focusing on local government, actively promoted TEEB tools and decision-making plans for the management of regional and municipal biodiversity and ecosystems;
- **Business** - some businesses (such as Puma) started to examine the impacts and dependencies on ecosystems and biodiversity along their supply chain.

TEEB's priorities have also evolved in the context of the wider international discourse in this space, a key element of which has been the emergence of the 2030 Agenda for Sustainable Development and the associated Sustainable Development Goals (SDGs) – see **Box 1.1.**

Critically, a common feature of both the work to date in the implementation phase of TEEB and the emerging approach to development and doing business in a world committed to meeting the Sustainable Development Goals are the interconnections and interdependencies between social, economic and environmental problems and achievements. It is therefore also clear that the pursuit of solely private profit or value as measured by markets, which neglect both positive and negative social and environmental externalities and impacts, cannot be relied upon to deliver effective or efficient solutions. Further, there is an economic incentive for those agents from both the public and the private sector that benefit from the status quo to lobby for it to be maintained.

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[2] "TEEB for Business" led (TEEB 2011) to the creation of a "TEEB for Business Coalition" comprising business, institutional & government stakeholders, which was re-named the "Natural Capital Coalition" in 2013 and in 2016 published the "Natural Capital Protocol".

Box 1.1 TEEBAgriFood and the Sustainable Development Goals (SDGs)

The SDGs are a series of 17 internationally agreed, universally applicable goals that are recognized as indivisible and cover issues across the spectrum of development from poverty, food security and water security, through equity, health, access to decent work, peace and a stable natural environment. In an article, The Guardian (2017) linking the SDGs to food and agriculture, TEEB Study Leader Pavan Sukhdev outlines some of the challenges of implementation.

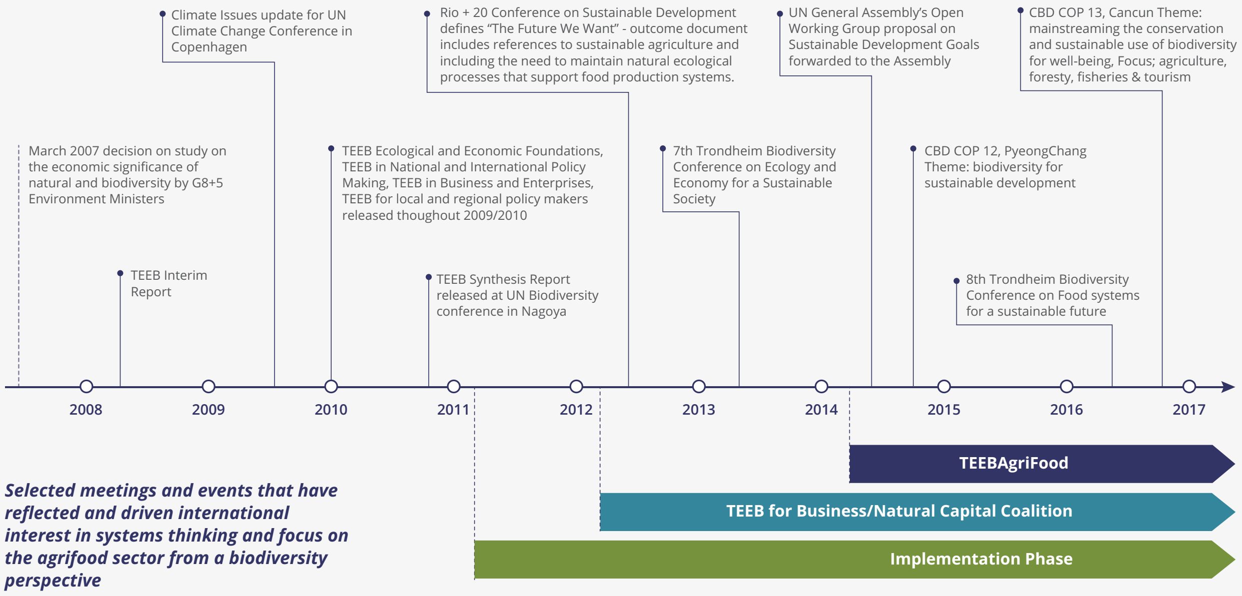
Indivisibility is key to the success of the SDGs as progress on one goal might be contingent on another, and this requires systems thinking. SDG 2 on zero hunger is perhaps most closely linked to TEEBAgriFood, but the fact that fish provide the main source of animal protein (and essential micronutrients) to more than one billion people globally implies that achieving SDG 2 also requires addressing SDG 14, on conserving and sustainably using the oceans. As Rockström and Sukhdev (EAT 2016) note, we are already using around 40 per cent of available land for growing food, a figure that is projected to rise to 70 per cent under a 'business and usual' scenario. How can achieving SDG 2 under this pathway then be compatible with achieving SDG 15 concerning life on land? The authors also note that the agri-food system also contributes over one-fourth of greenhouse gas emissions, so again achieving SDG 13 on climate change depends on how we tackle our goal of ending hunger, improving food security and improved nutrition. Our food choices also make a critical contribution to the global burden of disease, linking SDG 2 to SDG 3, the latter aiming to ensure good health and well-being. More broadly, global trends in shifts in the 'food plate' also do not auger well for achieving SDG 12 on responsible consumption and production. The analysis above points to the need for a 'joined up' approach and the application of systems thinking, i.e. not focusing on the delivery of kilocalories as the unifying performance metric of the agri-food sector, and this a core tenet of TEEBAgriFood.

Figure 1.1 The SDG 'wedding cake' (EAT 2016)

Rockstrom and Sukhdev further note that the delivery on the full range of SDGs is based first on achieving 'biospheric' or ecological goals (6, 13, 14, 15), i.e. it is a necessary but not sufficient condition of achieving social goals (such as SDG 1 on poverty and SDG 10 on reduced inequalities) and economic goals (such as SDG 8 on good jobs and economic growth) that we have resilient and stable ecosystems. This is reflected in their 'wedding cake' structure (see **Figure 1.1**). TEEB rests on a central tenet that ecosystems and biodiversity are primary and we must search for incentive mechanisms and achieve the enabling conditions to make them our core concern.

The focus of the current implementation phase of TEEB (2013 onwards) has included both demand-driven efforts to help build capacity for TEEB-style analysis of policy issues (at national, regional and local scale, as well as for businesses) alongside strategic interventions internationally to catalyse further efforts - reflecting the awareness of those involved in TEEB that it is not the only initiative in this space. TEEB developed (and continues to develop) a community of practice. The TEEB for Business Coalition (now the Natural Capital Coalition) was one of the first initiatives to develop from an initiative undertaken by the TEEB Study Leader and other key stakeholders in the TEEB for Business Report (TEEB 2012a) as set out in **Figure 1.2.** The Natural Capital Coalition was established to engage key stakeholders from business, government and civil society in open source collaboration in order to raise awareness and provide a leading-edge forum to shape the future of business thinking and action on 'natural capital', i.e. the critical role of properly functioning ecosystems in delivering economic prosperity.

Figure 1.2 TEEB timeline and connected global events (Source: authors)



Key work areas in the current implementation phase of TEEB have included business, water and wetlands, natural capital accounting, oceans, and of course TEEB for Agriculture and Food (henceforth 'TEEBAgriFood') – the subject of the current volume.

1.1.2 The emergence of demand for TEEB for Agriculture and Food

The agri-food sector featured in the earlier phase of TEEB. The range of outputs in this earlier phase were all built on the same foundations – the academic underpinnings from both the scientific and economic perspective, brought together in The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations (TEEB 2010b). This publication explored the values of biodiversity to agriculture, the trade-offs between different ecosystem services in agricultural systems, the cultural values of agricultural landscapes, as well as ideas of resilience and the potential value and the livelihood and environmental benefits of genetic variation in crops and crop wild relatives. The way that we produce and consume food and manage agricultural landscapes also featured in the TEEB publications developed for businesses (TEEB 2012a), for public policy makers at national level (TEEB 2011) and at local and regional level (TEEB 2012b), and in three of the 10 key recommendations in the TEEB Synthesis Report (TEEB 2010a). In short, the original TEEB studies (2007-2012) sought to highlight the depth of existing knowledge with respect to the interconnections between nature and food production.

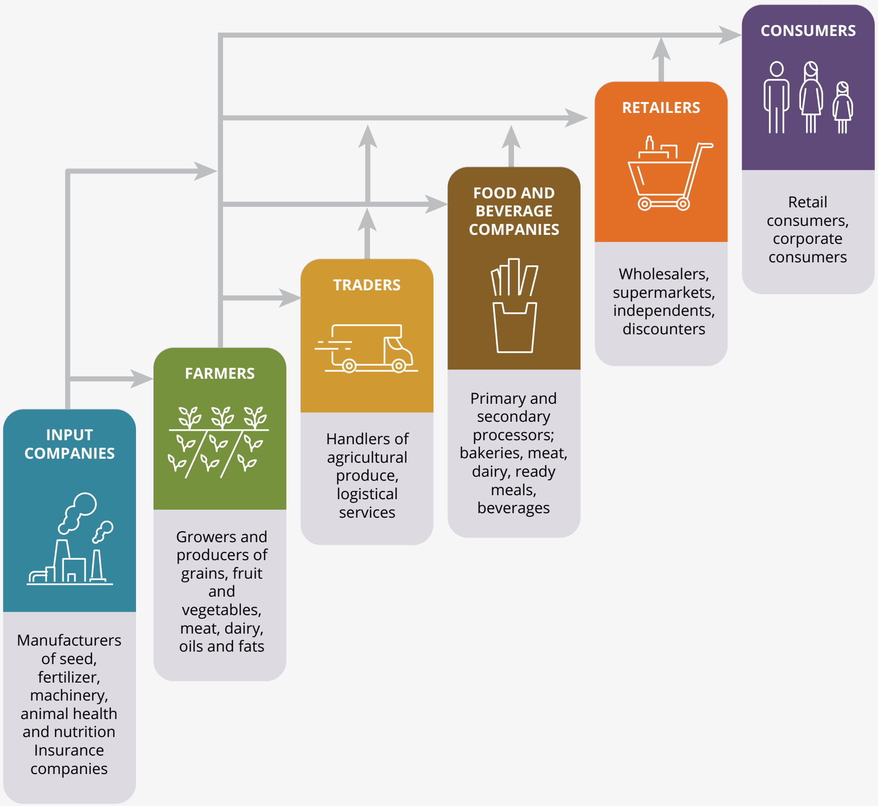
Although the agri-food sector did feature in the earlier phase of TEEB, the remit of TEEB was to 'correct the economic compass' by presenting appropriate ways of recognizing, demonstrating and then capturing the value of nature. Thus the earlier phase of TEEB considered the entire economy with its many industrial sectors. For an assessment of the eco-agri-food systems complex (as opposed to just the agri-food sector), a comprehensive understanding of all impacts and dependencies across the system, including externalities is required. This is the aim to which TEEBAgriFood seeks to contribute.

1.2 RATIONALE AND OBJECTIVES OF TEEBAGRIFOOD

1.2.1 TEEBAgriFood mission statement

The TEEBAgriFood study is designed to (1) provide a comprehensive economic evaluation of the eco-agri-food systems' complex, and (2) demonstrate that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive, and a lack of awareness of dependency on natural, social, human and produced capitals.

Figure 1.3 The food and beverage value chain (Trucost 2016)



1.2.2 What is the eco-agri-food systems compex?

Agriculture is an *economic sector*. It typically encompasses areas of economic activity beyond farm operations to include farm-related activities, such as processing, manufacturing and transport, so we may refer to it as the agri-food sector. There is a *value chain* in the sector, as set out in Figure 1.3, and there are systemic economic interlinkages and economic cross-dependencies in this value chain.

This economic system is underpinned by complex *ecological and climatic systems* at local, regional and global levels. Biodiversity and ecosystems – the study of which is at the heart of TEEB – underpin the delivery of economic output from this sector. Overlaying these natural systems are *social systems* influencing inter alia: (i) the composition of our food plates (i.e. what we eat), (ii) how we go about sourcing, purchasing, storing, cooking, and consuming food, and then discarding the food waste, (iii) our attitudes and behaviours towards farmers and the land that is used for agricultural production, and (iv) the way that cultural norms and values are transmitted between and across generations.

These three systems (economic, ecological and climatic, and social) interface and interact with each other, and that is why we refer to the 'eco-agri-food systems *complex*'.

In terms of a definition, as set out in the TEEBAgriFood Interim Report (TEEB 2015), the eco-agri-food systems complex is a collective term encompassing the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries[3], labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.

1.2.3 Why is there is a need to examine the externalities of eco-agri-food systems complex?

This question was tackled in depth in the TEEBAgriFood Interim Report and later summarized in an article for the journal Nature (Sukhdev *et al.* 2016). This article sets out the shortcomings of current patterns of crop and livestock production and of processing, transport and consumption with respect to what is required by society as a whole - the delivery of sufficient, healthy, nutritious food that does not damage nature.

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[3] Marine fisheries are out of scope of TEEBAgriFood.

The current eco-agri-food systems complex impacts both on human health and on the natural environment in detrimental ways; it is now the source of 60 per cent of terrestrial biodiversity loss, 24 per cent of greenhouse gas emissions, 33 per cent of soil degradation and 61 per cent of the depletion of commercial fish stocks (UNEP 2016). For example, failures in access and distribution contribute to the fact that 800 million people in developing countries consume less than the 2,100 kilocalories of food recommended by the World Food Programme whilst at the same time 1.9 billion people in the developed world consume more than 3,000 calories a day (FAO 2015). This imbalance also has wider ramifications. The impact of undernutrition across Africa and Asia is estimated at 11 per cent of Gross Domestic Product (GDP) annually (IFPRI 2016). Similarly, one in four adults are now overweight or obese, with obesity behind many of the chronic diseases that are sweeping the globe, from type 2 diabetes to heart disease. The World Health Organization has estimated the direct costs of diabetes alone at more than US$827 billion per year globally (WHO 2016).

The TEEBAgriFood Interim Report reflects on the role that agriculture plays in providing employment for around 1.3 billion people in a world that is already short of around 200 million jobs (ILO 2015). One billion of these jobs are in small-holder agriculture (less than 2 hectares) so it is important to address how society could provide alternative livelihoods for as many as 500 million more people if the concentration and mechanization of agribusinesses continues.

These are impacts on a global scale, yet in spite of the fact they are all connected to the same process (producing and consuming food), they have not yet been evaluated as an entire system, using a systems approach.

From a human health perspective, the Global Panel on Agriculture and Food Systems for Nutrition (2016) includes a call to scientists, governments and donors to work out how to craft and sustain food systems to provide nutritious diets for all. The report authors highlight that SDG 2 (zero hunger) and SDG 3 (good health and wellbeing) cannot be achieved with piecemeal action: “the trends are so large and so interconnected that the entire system needs overhauling” (Haddad *et al.* 2016, p.31). The emergence of initiatives such as The Food and Land-Use Coalition (FOLU) , the International Panel of Experts on Sustainable Food Systems (IPES-Food) and the High Level Panel of Experts on Food Security and Nutrition (HLPE) , each of which aims to bring together change agents in this space, shows that decision-makers understand the need for change and are ready to act.

Similarly, the emergence of the planetary health agenda, which is building a better understanding of the ramifications of environmental change on human livelihoods, pushes the need for more resilient food and agricultural systems that address both undernutrition and overnutrition, reduction of waste, diversification diets, and minimization of environmental damage. The impacts arising from feedbacks in the system from our current behaviour are likely to be profound. The Lancet Commission on Planetary Health’s report (Whitmee *et al.* 2015) estimated climate change will result in 250,000 additional deaths between 2030 and 2050, that soil degradation leads to the loss of 1–2 million hectares of agricultural land every year, and that by 2050 40 per cent of the world’s population could be living in areas under severe water stress. The connections to food systems are clear, especially in terms of some of the identified solutions for a healthier planet - reducing food waste, halting deforestation, using water more efficiently and supporting healthier, lower environmental impact diets.

The need to bring together the environment, human health and human development agendas is increasingly evident. This is illustrated neatly by the impact of Kate Raworth’s recent book *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist* (Raworth 2017) which aims to define both an environmentally-safe and socially-just space for humanity and assess how economies need to change to achieve this. This builds on the notion of planetary boundaries and the safe operating space within which human systems can operate, with its accompanying environmental limits. Juxtaposing this with factors which can cause human deprivation can be useful in assessing options to allow people to thrive within the limits of the planet. This thinking is very much embedded within the holistic approach advocated in this current TEEBAgriFood report.

Irrespective of the particular socio-economic, cultural and ecological context in which a particular eco-agri-food system is situated, there are always positive and negative externalities and impacts across the entire value chain, i.e. from production, through processing and transport, to final consumption. The question is thus not whether such externalities and impacts exist but rather their extent, which agents in society are affected, and whether we can promote a decision-making environment in which the positive impacts flourish and the negatives are mitigated.

1.2.4 Why should TEEB be examining the externalities of eco-agri-food systems?

The demand for a TEEB study on eco-agri-food systems was based on at least three key understandings: (1) the extent of the positive and negative externalities (i.e. non-compensated impacts on third parties) of the agri-food sector are likely larger than that of any other sector; (2) the approaches applied to date have been inadequate owing in part to the lack of a coherent, universal evaluation framework that includes these disparate externalities along with useful metrics; and (3) the TEEB community can develop, communicate and operationalize such an evaluation framework, and thereby contribute significantly to the integrity and functioning of ecosystems and to improving human livelihoods.

With respect to the first of these - the extent of externalities in the agri-food sector - an important report entitled "Natural Capital at Risk: The Top 100 Externalities of Business" (Trucost 2013) intended to help reveal the business case for further private sector engagement with the issue of natural capital and to help prioritize actions. It examined a wide range of impacts of business on the natural environment – the effects of which tend not to be reflected in the market prices of associated financial transactions (hence termed 'externalities').

The report looked at different types of non-market impacts on natural capital across different sectors and in varying regions of the world. The top 100 – ranked by the estimated monetary value of the impacts – were presented in the report. Whilst the research was open about the limitations in its the valuation approach, the magnitude of the figures highlighted the need for attention. The top 100 externalities had an estimated cost of around US$4.7 trillion per year in terms of the environmental and social costs of lost ecosystem services and pollution. Crucially, in the context of TEEBAgriFood, 11 out of the top 20 externalities were related to agri-food sectors, ranging from the land impacts of cattle ranching in South America, to the water use impacts of wheat production in East Asia and corn production in North Africa.

In 2014, the Natural Capital Coalition (formerly the TEEB for Business Coalition) launched the Natural Capital Protocol, which provides a framework to help businesses begin to explore their relationship with nature. Reflecting the frequency with which agri-food sectors appeared in the top 100, a food and beverage sector supplement was released in 2016. The Protocol highlights from a business perspective the interconnections across agriculture and food systems and the varying degrees of resulting horizontal and vertical integration, underscoring the need to look system-wide to understand how to drive change. The supplement itself provides practical details and applied examples to help businesses in the food and beverage sector think about and take account of their impact and dependencies on natural capital in their decision making and planning.

What the "Natural Capital at Risk: The Top 100 Externalities of Business" and the food and beverage supplement tell us is that there is a need to tackle the externalities in the sector, and that TEEBAgriFood is not alone in recognizing this need. TEEBAgriFood offers a unique value-addition in this space in that the TEEBAgriFood Evaluation Framework (hereafter 'Evaluation Framework' or 'Framework') presented in Chapter 6 of this report is both *comprehensive* and *universally applicable*, and applies a *systems perspective* (described in Chapter 2).

There are myriad externalities and impacts – both positive and negative – created in the production and consumption of food. The Evaluation Framework is designed to be comprehensive. For instance, there is a focus not just on the impacts and dependencies between the agri-food sector/ecosystems and biodiversity but also on the agri-food sector's contribution to human health outcomes. This has also meant that the TEEB community of practice has been extended for TEEBAgriFood to include academics, policy-makers, civil society groups etc. operating in the human health and nutrition fields.

A challenge, which is perhaps unique to the agri-food sector, is the extent of the heterogeneity within and across food systems. The Natural Capital Protocol's food and beverage sector guide is targeted at business. In many ways, all agribusinesses are firms of one kind or another but small-scale producers are unlikely to have the same objectives and constraints as large firms. One size does *not* fit all in this sector. TEEB from its inception has championed the 'GDP of the Poor' therein flagging the particular dependence of the poorer segments of society on well-functioning ecosystems, and thus developing and applying a universal Evaluation Framework that is applicable to scenario analysis for small-scale producers. But equally the Framework must be (and indeed is) applicable to large-scale agribusiness.

Systems thinking is central to TEEBAgriFood. It is not possible or sensible to isolate impacts and dependencies of primary agricultural production (within the farm gate) from the rest of the eco-agri-food system if we are to find truly sustainable and equitable solutions. Issues cut across current commodity productions systems and across spatial and temporal scales. Analyses will need to be context-specific. TEEBAgriFood sets out and illustrates a comprehensive system-wide analytical lens that can be used to examine different issues given this need.

It is recognized that TEEB engages substantially with the issues around agriculture and food. The TEEBAgriFood Interim Report (TEEB 2015) was noted by the 13th Conference of the Parties of the Convention on Biological Diversity in Cancún in December 2016 in the context of a decision focused on "actions to enhance the implementation of the Strategic Plan for Biodiversity [agreed in 2010]", which specifically highlights efforts with respect to mainstreaming the integration of biodiversity within and across sectors. Recognition is growing that problems of biodiversity loss cannot (and should not) be tackled by conservationists alone, but rather by society at large including the business community.

This report builds substantially on the TEEBAgriFood Interim Report (TEEB 2015), focusing on developing the Framework and analysis on which transformations can be based. It is therefore both timely and urgent – it is essential that such a change in how we look at our food systems is adopted and used quickly.

1.3 STRUCTURE OF THE REPORT

The aspiration of the TEEBAgriFood *project* is to change the way that we produce and consume food, so as to reflect the hitherto invisible positive and negative externalities and impacts in the eco-agri-food systems complex. This *report* – the 'Scientific and Economic Foundations' report - focuses on the need to 'make the case' for this new paradigm. As such, this report contributes to the aspiration of the TEEBAgriFood project but needs to (and will) be complemented by: (1) other reports targeted at specific change agents, (2) projects where change is tested and implemented at corporate, regional, national and supra-national levels, and (3) communications and outreach.

Following this Introductory chapter, the report is divided into four segments, as per sections 1.3.1-1.3.4 below. **Figure 1.4** provides a schematic representation of the entire eco-agri-food systems complex - the visible and invisible flows of agricultural production. This figure is used below to illustrate the rationale for the chapter ordering and the narrative thread of the report.

1.3.1 The lens through which we analyse the eco-agri-food systems complex – the systems approach

Chapter 2 lays out the foundation for using systems thinking as a guiding perspective in TEEBAgriFood. This is required so as to understand the relationships across multiple sectors, disciplines and perspectives, thereby embracing holism and avoiding reductionist, 'silo' thinking. Systems theory emphasizes circular flows with both negative and positive dynamic feedbacks between the economy, the environment and human social systems. Applying a systems approach requires looking at feedbacks across the entire value chain from 'agricultural production' through to 'household consumption' via 'manufacturing & processing' and 'distribution, marketing and retail', while analysing multifarious impacts and dependencies (*c.f.* **Figure 1.4**).

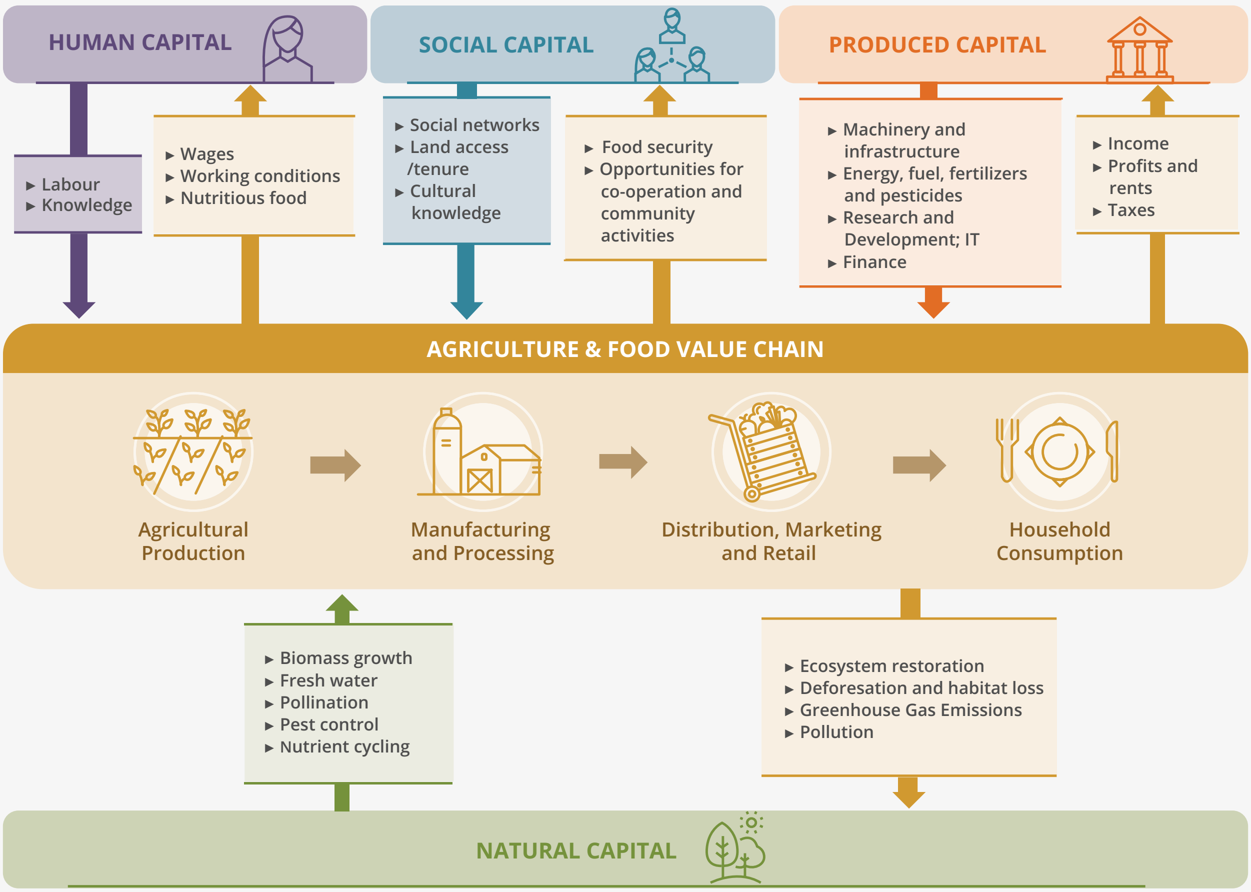
1.3.2 Evidence that we need to change the eco-agri-food systems complex

Since the metric commonly used to assess on-farm economic performance has (and continues to be) yield/hectare, agricultural systems research has focused on irrigation, breeding, machinery etc. – the visible inputs to the agricultural system in the schematic. These include – with reference to **Figure 1.4** - 'labour' (from human capital), and 'manufacturing and infrastructure' and 'energy, fuel, fertilisers and pesticides' (from produced capital). TEEBAgriFood aims to *change food metrics*. Chapter 3 sets out the available scientific data and evidence not just on the visible flows in **Figure 1.4** but also those that tend to be invisible, with a particular focus on the flows coming from natural capital. Some flows can be visible or invisible depending on circumstances. For instance, agri-tech consultancies market their 'knowledge' (from human capital) to large-scale commercial producers in 'manufacturing & processing', but local indigenous knowledge of crop varieties – although critical to maintaining resilient social communities – might remain invisible.

The TEEBAgriFood assessment acknowledges and explores the heterogeneity across agricultural systems and finds that positive and negative externalities and impacts are pervasive across all eco-agri-food systems, and further across the value chains in which these systems are situated.

'The way we produce, process, distribute, and consume food (as well as how we deal with its disposal) impacts human health and nutritional security, which in turn (with reference to **Figure 1.4**) impacts on the availability of 'labour' and on the types of 'social networks'. Chapter 4 focuses on this subject, looking across the entire value chain. Six of the top 11 risk factors driving the global burden of disease are diet related. The quality of life for billions of people is impacted by malnutrition. Across the food system, people can additionally be impacted via work-related injuries (or death) or toxin/pathogen exposure. Coupled with these direct food system impacts are indirect impacts that are felt now and will be felt in future generations. The food system can be either an enabler of food and nutrition security, livelihood procurement, and environmental sustainability, or it can be a disabler. We can develop food systems that allow a large number of individuals to secure a livelihood through the food system or one in which large numbers of food system workers are systematically exploited. This chapter explores a number of endpoints in various food system strategies and suggests a strategy for exploration, mitigation, change, and ultimately transformation of our global food system to one in which health – human, ecosystem, and community – is the norm for 9-10 billion people.

Figure 1.4 Capital stocks and value flows in eco-agri-food systems (Source: authors)



All of the choices that we make vis-à-vis food - as individual consumers or citizens, as farmers, as fiduciary agents of agribusiness corporations, as part of sub-national, national or global policy-making - have an ethical dimension. In an equitable food system, all people have meaningful access to sufficient healthy and culturally appropriate food, and the benefits and burdens of the food system are equitably distributed. This is the focus of Chapter 5. The overall objective of this chapter is to identify key aspects of social equity of the world's food systems in order to provide pathways and indicators that can be used to assess the impacts of food systems in equity outcomes.

Chapters 3-5 collectively provide evidence that: (i) the wrong metrics are being used to assess the eco-agri-food systems complex; (ii) applying today's metrics leads to outcomes that degrade the ecosystems and biodiversity that agricultural systems depend on, and negatively impact on human health; and (iii) these burdens fall disproportionately on the poorer segments of society. Chapters 3-5 express the *need for a change in the metrics*. Chapters 6-8 set out TEEBAgriFood's *proposal for such a change* in the form of the Evaluation Framework.

1.3.3 The TEEBAgriFood Evaluation Framework: a tool to assess the eco-agri-food systems complex

Chapter 6 sets out the Framework. The Framework highlights all relevant dimensions of the eco-agri-food value chain and pushes policymakers, researchers, and businesses to include these in decision-making. These dimensions include social, economic, and environmental elements as well inputs/outputs across the value chain. The Framework therefore establishes all of "what should be evaluated".

Guiding principles are that the Framework is comprehensive (covering all elements), universal (be applicable to all decision-making contexts), and supports multi-criteria assessments (e.g. production, consumption, greenhouse gas emissions, fertilizer use, health impacts and decent work).

Whereas Chapter 6 is concerned with what to value, Chapter 7 turns to "*how* to carry out the evaluation." The chapter makes the distinction between (and presents examples of) methods for the *economic valuation* of ecosystem services and disservices in both monetary and non-monetary terms, *evaluation* methods, and *modelling* tools and techniques. Policy-makers are unlikely to rely solely on the outcomes of an economic valuation study, but such information can be an important component in decision-making. Valuation results might be used as *an input to* an evaluation approach such as Cost Benefit Analysis or Multi-Criteria Analysis, which may be informed by (for example) Systems Dynamics modelling. Chapter 6 provides an illustrative example of integrated modelling in Kilombero, Tanzania to help explain the distinction between valuation, evaluation and modelling.

One of the guiding principles for the Framework as mentioned above is universality. The objective of Chapter 8 is to provide case study examples of five clusters of possible applications: (i) agricultural management systems; (ii) business analysis; (iii) dietary comparison; (iv) policy evaluation; and (v) national accounts for the agriculture and food sector.

The examples in Chapter 8 illustrate not only how a published study fits into the Framework but also *equally how it does not*. We argue that the broad methodological approaches required to apply Framework testing do already exist (and are presented in Chapter 7) but, as with any paradigm shift, the data and results from studies that pre-date the Framework are not adequate for a full Framework application. Thus gaps are to be expected.

The aim of the final two chapters in this report is to explore what has to change in order for us to realize this paradigm shift – for the Framework to become the new orthodoxy.

1.3.4 How do we change the eco-agri-food systems complex?

Chapter 9 on the theory of change seeks to explore how attempts to redirect the eco-agri-food systems complex might be perceived from the perspectives of key actor groups, suggesting avenues to escape 'path dependencies' that lock in unsustainable practices. What form might such path dependency take? It may be the case that individual farmers or agribusinesses see the benefit of a transformative shift in the way that food is produced and, were they all to *collectively and simultaneously* agree to shift behaviours, they could then operationalize this transformative change. But concerted and coordinated actions are required in such instances, and there are strong corporate (and sometimes cultural) forces that dissuade these farmers and agri-businesses from shifting from the dominant orthodoxy. They are 'locked into' an unsustainable path dependency.

Chapter 9 explores pathways towards sustainability. Information alone often fails to motivate change. Manipulation of data has led consumers to doubt scientific results, serving special interests at the expense of public benefit. The chapter sets out a range of actor-relevant theories of change. These include consumer advocacy (e.g. the threat of boycotts and reputational risk), product certification, promoting institutional and societal learning, developing strategic alliances etc.

Part of the impetus for the transformative shift discussed above will likely come from TEEBAgriFood aligning itself with on-going initiatives and processes, be they global agreements or business-led initiatives, and demonstrating the value-added of the Framework. This is the subject of Chapter 10. Such global initiatives include the Right to Food, the Aichi Targets, and (as discussed earlier in **Box 1.1**) the 2030 Agenda and its Sustainable Development Goals. Linking TEEBAgriFood to business platforms is important in that they support learning and, if linked to citizen representation, can enhance accountability.

1.4 THE TEEB APPROACH: REPLICATING THE SUCCESS OF EARLY TEEB WORK FOR TEEBAGRIFOOD

It is the belief of those who have been involved with TEEB throughout its development that the initiative's success and longevity are not solely due to the compelling narrative behind the work, but also its delivery approach. TEEB work is not only deliberately open and transparent, but also reliant on the communities of practice that it aims to foster and develop. Through open and widely publicized calls for evidence, both the original TEEB work and TEEBAgriFood reached out to this community to gather evidence and to encourage further development and uptake of best practice.

Change cannot be realised without developing a community that connects researchers and decision makers across different sectors. This is a critical element of the way TEEB works. It is our hope that the reader of this report will be inspired to become part of this community, which is not just focused on knowledge generation, but the connection of this knowledge to those who can influence chang.

TEEB's governance structure is also supportive of this. The TEEB initiative is coordinated through the TEEB office situated in UN Environment and geographically based in Geneva, Switzerland. The overall TEEB initiative is guided by a high-level independent Advisory Board with members spanning government, business, academia and civil society, and TEEB study leader and UN Goodwill

Ambassador Pavan Sukhdev. It is also supported by a Coordination Group, including those working directly on the TEEB work programme and policy makers from supporting countries. This helps to ensure links to ongoing international policy processes and to see that TEEB responds to and is relevant in the context of international demands.

As it is a major new undertaking, the TEEBAgriFood study also has its own Project Steering Committee (chaired by Alexander Mueller, the TEEBAgriFood Study Leader), whose members are more substantively engaged in the TEEBAgriFood work, providing support in various forms including expert contacts, direct input and guidance and peer review. Summaries of the governance structure and work to date on this project are readily available via the agriculture and food section of the TEEB website http://www.teebweb.org/agriculture-and-food/.

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CHAPTER 2

SYSTEMS THINKING: AN APPROACH FOR UNDERSTANDING ‘ECO-AGRI-FOOD SYSTEMS’

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SUMMARY

Chapter 2 makes the case for using systems thinking as a guiding perspective for TEEBAgriFood's development of a comprehensive Evaluation Framework for the eco-agri-food system. Many dimensions of the eco-agri-food system create complex analytical and policy challenges. Systems thinking allows better understanding and forecasting the outcomes of policy decisions by illuminating how the components of a system are interconnected with one another and how the drivers of change are determined and impacted by feedback loops, delays and non-linear relationships. To establish the building blocks of a theory of change, systems thinking empowers us to move beyond technical analysis and decision-tool toward more integrated approaches that can aid in the forming of a common ground for cultural changes.

CONTENTS

FIGURES, BOXES AND TABLES

CHAPTER 2

2.0 KEY MESSAGES

- This chapter makes the case for using systems thinking as a guiding perspective for TEEBAgriFood’s development of a comprehensive Evaluation Framework for the eco-agri-food system.
- ‘Eco-agri-food systems’ is our collective term for the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.
- Diverse agricultural production systems grow our crops and livestock and employ more people than any other economic sector. They are underpinned by complex biological and climatic feedback loops at local, regional and global levels. These natural systems are overlaid by social and economic systems, which transform agricultural production into food and finally deliver it to people based on market infrastructure, economic forces, government policies, and corporate strategies interacting with consumer and societal preferences. Furthermore, technologies, information and culture are continually re-shaping production, distribution and consumption, as well as the interactions among them.
- The global food system is one of the most important drivers of planetary transformation and it is experiencing multiple failures. Many dimensions of the eco-agri-food system create complex analytical and policy challenges. In the end, the state of human wellbeing, including the health of people and the planet, are determined by these diverse interlinked “eco-agri-food systems” and consumer choices made within these systems.
- Eco-agri-food systems are more than production systems. Using one-dimensional metrics such as “per hectare productivity” ignores the negative consequences and the trade-offs across multiple domains of human and planetary wellbeing and fails to account for the various dimensions of sustainability.
- Silo approaches are limiting our ability to achieve a comprehensive understanding of the interconnected nature of the eco-agri-food system challenges. We need a holistic framework that allows the integration of well-understood individual pieces into a new, complete picture.
- Systems thinking allows better understanding and forecasting the outcomes of policy decisions by illuminating how the components of a system are interconnected with one another. Systems thinking identifies the drivers of change as determined and impacted by feedback loops, delays and non-linear relationships. Synergies and coherence can be gained when evidence is generated and used based on concepts and methods aligned with systems thinking.
- In the context of TEEBAgriFood, an important role of systems thinking is to identify the main components, drivers, dynamics and relationships that impact the entire value chain of the eco-agri-food system. This helps make side effects and tradeoffs visible, allows for identification of winners and losers, and uncovers synergies that can be realized through the implementation of public policies or other behaviour interventions.
- To establish the building blocks of a theory of change, systems thinking empowers us to move beyond technical analysis and decision-tool toward more integrated approaches that can aid in the forming of a common ground for cultural changes.

CHAPTER 2

SYSTEMS THINKING AN APPROACH FOR UNDERSTANDING ‘ECO-AGRI-FOOD SYSTEMS’

2.1 INTRODUCTION

Our crops and livestock arise from diverse agricultural production systems that employ more people than any other economic sector globally (ILO 2014). These production systems are underpinned by complex biological and climatic systems at local, regional and global levels. Overlaying these production systems are social systems, including those involved with agricultural production and the transformation of crops into food, fuels and fibre. A third layer consists of economic systems, which deliver agricultural products to people, based on market forces, available infrastructure, government policies, and corporate strategies, all of which interact with consumer preferences and broader societal norms. Many of the interactions, both within and across systems, involve “externalities” (positive or negative), described in economics as the cost or benefit that affects a party who did not choose to incur that cost or benefit (Buchanan and Stubblebine 1962). Furthermore, technologies, information, divergent views, and culture are continually re-shaping production, distribution, and consumption modes, as well as the interactions among them. In the end, the state of many dimensions of human wellbeing, including the health of people and of the planet, are affected by the diverse interlinked food systems and the consumer choices made within these systems. In this report, the eco-agri-food system refers to the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.

The global food system, one of the most important drivers of planetary transformation (Rockström *et al.* 2009a; Rockström *et al.* 2009b; Ehrlich and Ehrlich 2013), is “failing”, and the “business-as-usual” model is not working (Vivero-Pol 2017; IFPRI 2016; IAASTD 2009; Rosin *et al.* 2012a; Rosin *et al.* 2012b). The Global Food Policy Report (IFPRI 2016, p.6) points out the failures of the current food system:

> *On the one hand, it feeds more than 6 billion people—more than many in earlier decades and centuries would have believed possible. On the other hand, it leaves nearly 800 million people hungry. It does not provide all people with a healthy, safe, and nutritious diet; many of those who get sufficient calories are still malnourished. The food system does not generate adequate livelihoods for millions of people employed in the food system. And in a context of scarce and degraded natural resources and advancing climate change, it is not environmentally sustainable.*

Humans are the main driver of change in the epoch in which we live, the new geological era some refer to as the Anthropocene (Rockström *et al.* 2009a; Steffen *et al.* 2011; Steffen *et al.* 2015). Much of this transformation has been driven by the commercialization of production and the mechanization of agriculture globally (see **Box 2.1** for an example), but failure by markets and governments to address externalities that affect social and environmental integrity have also contributed to the problem. The negative impact of human activity on the natural world has reached crisis levels. Terrestrial vertebrate populations declined by an astonishing 58 per cent between 1970 and 2010 (WWF 2016). Invertebrate populations show a global decline of about 45 per cent over the past 40 years (Dirzo *et al.* 2014). Similar declines have been documented for marine species (McCauley *et al.* 2015). Much of this decline in wildlife is attributed to habitat loss, pollution and over-exploitation associated with food production systems (Rockström *et al.* 2009a; Godfray *et al.* 2010; Amundson *et al.* 2015). Livestock production is the largest source of anthropogenic alteration to global phosphorus and nitrogen cycles. Since the 1950s, surpluses in these nutrients have increased by a factor of four and five, respectively (Bouwman *et al.* 2013). Excess quantities of these nutrients entering waterways are the leading causes of freshwater and marine eutrophication and the emergence of dead zones affecting aquatic life. Soil loss and terrestrial nutrient depletion are also accelerating (Baveye *et al.* 2016).

Furthermore, the expansion of industrial agriculture in many cases has had adverse social consequences for human communities (Ehrlich and Ehrlich 2013). Land-insecure smallholders, family farmers and peri-urban settlers are being pushed off land they have traditionally cultivated in many parts of the world, in the face of commercialization and the purchase of large tracts of land by foreign or absentee investors (De Schutter 2011; Rulli *et al.* 2013; Thorn *et al.* 2015). Many such cases have been documented in Latin America (Arancibia 2013; Carrizo and Berger 2012; Lapegna 2013; 2017; Leguizamón 2014a). In addition to a host of social impacts, such displacement leads to the loss of the local, experiential knowledge that is essential for site-appropriate agricultural production practices. Locally adapted cultivars and breeds may be lost, reducing agricultural biodiversity.

Seeking an ecologically sustainable and socially fair transition out of the current crisis has become an issue of utmost priority (Vivero-Pol 2017). Multiple voices have called for a paradigm shift in the structure and operation of the global food system (IAASTD 2009; Watson 2012; Rosin *et al.* 2012b), although the values, narratives, economic and moral foundations of that new aspirational and inspirational paradigm have not yet been fully developed (Vivero-Pol 2017). The application of systems thinking to understanding and managing the complexity of the global eco-agri-food system is an important step in achieving this transformation (Bosch *et al.* 2007; UNEP 2011). (TEEBAgriFood sets out to evaluate the reality of today's highly complex "eco-agri-food" systems. By making the invisibles (externalities) visible, the society will be better positioned to take into account the impacts of activities that have previously been ignored.

Traditionally, scientists have assessed or analysed components or subsystems of the eco-agri-food system in individual studies. The goal has been to improve the efficiency of each component, based on the assumption that this will also improve the efficiency of the whole system. However, little attention has been paid to connecting the pieces of this puzzle to achieve a comprehensive understanding of what takes place in reality. Indeed, a holistic framework that allows the integration of these pieces into a new, full, picture has thus far been lacking. Using money as the common unit, economists have focused on aspects that can be readily identified, traded and monetized. However, this has left social and environmental impacts along value-chains insufficiently considered or valued, especially if they are financially invisible. By emphasizing evidence-based choices, political decision makers have relied on best estimates and expert knowledge, taking into account only those pieces of the puzzle that are well researched and leaving out much local, traditional and indigenous knowledge. Moreover, the lack of information flow between scientists, practitioners and policy makers exacerbates these shortcomings, contrary to increased emphasis upon evidence-based policy (Pretty *et al*. 2010). Despite evidence of the interconnectedness of challenges across sectors, the current political and scientific incentive structures do not reward integrated approaches that address linkages, time delays and feedback loops, which cut across multiple sectors and disciplines, to seek shared solutions. The consequences, trade-offs and impacts left unaddressed, too frequently work against achieving sustainability in the eco-agri-food system overall.

As population and inequity increase worldwide, critical questions arise regarding how we can produce and distribute food of high nutritional quality in order to feed a growing global population in a sustainable manner (Foresight 2011). Future policy decisions will increasingly pit multiple domains of ecological sustainability, economic development, and human well-being against one another, but this growing complexity cannot be a cause for inaction. Systems thinking, which focuses on the identification of interrelationships between components, is urgently needed to help us find areas where synergies are possible and where interventions will have the most impact, as well as identify where trade-offs must be recognized and negotiated.

The ambition of the TEEBAgriFood evaluation is to improve the conditions for integrated decision-making for a more sustainable eco-agri-food system. This can only be convincingly done by taking a systems approach to understand how the eco-agri-food system functions within natural and social systems, while at the same time considering cultural narratives and the need for transformational change. To achieve this, the contributions of natural and social capital to the eco-agri-food system need to be made visible. This implies not only focusing on production processes, but also on multiple interactions, feedback loops, and pathways by which the environment and agriculture contribute to human health and well-being. This calls for redoubling efforts to uncover the values of services of nature and roles of social capital not accounted for in the market economy (TEEB 2015) and the full benefits and costs of the eco-agri-food system across all stages of the value chain. Moreover, the notion of developing a "full" picture is in itself value-laden, critically dependent on what is included (hinging on the nature of knowing and knowledge), what matters to whom, and how we structure, reason, connect and interpret what we see (our underlying perspective or worldview, epistemic beliefs and assumptions). Considering such factors requires discovery of and appreciation for the epistemological views of different social actors, which are inherently value-laden, in order to form a common ground for cultural changes.

The health of our planet and its population depends on bringing together all components of the eco-agri-food system for study and decision-making within an integrated framework. We need a framework where we can understand that dzud1 in Mongolia, protectionism in

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1 A Mongolian term for summer drought followed by a severe winter, generally causing serious loss of livestock.

Europe, political change in the U.S., corporate take-over of family agriculture in Australia, or land grabbing in Africa all affect the quantity and quality of food on global markets, the stability of impoverished states, and the functioning of ecosystems in seemingly unconnected parts of the world. We need a framework that can capture how the increasing demand for red meat in Asia could degrade soils in Australia, lead to greater extinction of yet-to-be-discovered insects, and contribute to the socio-economic collapse of small rural towns. Globalization has created an interconnected global community. We now need a systems-based framework that can help us connect the dots and understand the relationships across multiple sectors, disciplines and perspectives for improved decision-making. Any framework will have limitations, but the one contained in this report was created with the intent to capture as many factors as possible in order to achieve a more holistic understanding and accurate evaluation of the eco-agri-food system.

Understanding the complexity of the eco-agri-food system and its importance for both the health of people and the planet requires systemic analysis based on a comprehensive evaluation framework. This chapter articulates the need for using systems thinking as a guiding perspective for TEEBAgriFood's development of such an Evaluation Framework.

While the empirical evidence of the challenges faced by the eco-agri-food system and the consequences of failing to take a systems view are elaborated in Chapters 3, 4 and 5, this chapter explores the role of systems thinking in achieving a more sustainable eco-agri-food system, by lending conceptual support for the development and application of the TEEBAgriFood Evaluation Framework (Chapters 6, 7 and 8). Going beyond the Framework to explore other building blocks, including a theory of change and its application, are explored in Chapters 9 and 10.

In this chapter, following the introduction, Section 2.2 explains why we need systems-based analytical tools. An eco-agri-food system is more than just a production system. Its multiple dimensions create complex analytical and policy challenges that require inclusive conceptualizations and analytical tools. Section 2.3 introduces what systems thinking has to offer, and explains how a systems approach, including conceptualization, investigation and quantification, can contribute to informed decision-making by integrating the key components of the eco-agri-food system, i.e. their economic, social, health, ecosystem, and environmental dimensions. It also demonstrates the application of a systems approach in understanding the eco-agri-food system and evaluating options for future changes to the system. Finally, Section 2.4 concludes with key messages.

Box 2.1 Case study: Pushing the ecosystem beyond its critical safe boundaries in the Argentine Pampas during the 20th century (Source: Viglizzo and Frank 2006)

The Pampas of Argentina are a large and complex sand dune system that formed during the last era of Pleistocene glaciations and later semi-desertic episodes. Humans only colonized the region during the last century, but their action was powerful enough to push the ecosystem beyond its safe operating boundaries and trigger two catastrophic events: one during the first half of the century, and the other during the second half. Deforestation and de-vegetation, over grazing and over cropping plus a non-suitable tillage technology, in interaction with extremely dry and windy conditions of the 1930s and 1940s, caused a large dust-bowl episode that led to severe dust storms, cattle mortality, crop failure, farmer bankruptcy and rural migration. During the second half of the century, improved rainfall conditions favoured the conversion of abandoned lands into grazing lands and croplands. At the same time, recurrent episodes of flooding affected the area between 1970 and 2017, more drastically in the highly productive lowlands of the area. The configuration of dunes with respect to slope, and the lack of a suitable infrastructure, impeded water removal and favoured its accumulation. The expansion of the cultivation frontier with annual crops provoked a rapid rise in the water table, which dramatically increased the severity of floods during humid periods. Both ecological collapses during the 20th century were the result of a complex interaction of geological configuration, climate variability and human intervention. Over cropping likely surpassed critical ecological thresholds in the area and this, in turn, triggered both the dust bowl and the flooding events. On the other hand, natural feedback mechanisms activated by such events helped with the stabilization and recovery of the affected lands.

2.2 WHY ARE SYSTEMS-BASED ANALYTICAL APPROACHES NEEDED?

2.2.1 Eco-agri-food systems are more than production systems

Agriculture and food systems have typically been evaluated based on their yield, with research aimed at increasing productivity, rather than on more holistic, integrative natural resources management (NRM), and even less on equitable food access and nutritional security (IAASTD 2009). Using one-dimensional metrics such as "per hectare productivity" is highly problematic as it ignores the negative consequences (i.e., externalities of individuals' choices/activities and of policies) and the trade-offs across multiple domains of human and planetary wellbeing and the various dimensions of sustainability. Eco-agri-food system and sustainability challenges are tightly linked (Liu *et al.* 2015); however, these are most often studied in isolation. This isolation is a reason for the failure of food systems to provide healthy diets to the global population, and a major driver of pushing us beyond multiple planetary boundaries (Rockström *et al.* 2009).

The world has experienced an extraordinary growth in crop yield since the 1960s due to investment in crop research and infrastructure, and thanks to market development and government support (Pingali 2014). While human populations more than doubled during 1960-2010, the Green Revolution enabled a threefold increase in the production of cereal crops, with only a 30 per cent increase in cultivated land area (Wik *et al.* 2008). The share of undernourished people decreased from 24 per cent in 1990-91 to 13 per cent by 2012 (Thorn *et al.* 2016; FAO 2015). However, this singular focus on yields has had important environmental costs. The IPCC estimated that roughly one-fifth of the total anthropogenic emissions of greenhouse gases during the 1990s originated from land use changes (Goldewijk and Ramankutty 2004). The intensification of agriculture has had negative consequences on water availability, soil degradation, and chemical runoff, with impacts beyond the areas cultivated (Burney *et al*. 2010). Part of these externalities have been "internalized" within agriculture as manifested in the slowdown in yield growth observed since the mid-1980s, which can be attributed, in part, to the degradation of the agricultural resource base. But much of the externalities remain unaddressed. These environmental costs are widely recognized as a potential threat to the long-term sustainability and replication of the Green Revolution success (IAASTD 2009; Webb 2009; Pingali and Rosegrant 1994). Some authors have pointed out that the environmental consequences were not caused by the Green Revolution technology *per se*, but rather by the policy environment that promoted overuse of inputs and the injudicious expansion of cultivation into areas that could not sustain high levels of intensification (Pingali 2014). Seppelt *et al*. (2014) show that the peak-rate years (defined as the year of maximum resource appropriation rate) for many of the world's major resources are synchronized (i.e., occurring at approximately the same time in the history of human civilization), suggesting that multiple planetary resources have to be managed simultaneously when assessing the likelihood of successful adaptation of the global society to physical scarcity.

The overemphasis on productivity has also imposed significant costs on human health and contributed to inequity. By 2013, several of the top risk factors driving disease globally were related to diet (GBD 2013 Risk Factors Collaborators 2015). Current food systems over-produce products of low nutritional value and even harmful foods such as sugary drinks, driven by political and corporate interests (Mintz 1985; Richardson 2009), while significantly under-producing many beneficial foods such as seeds and nuts, fruits and vegetables, as noted in the Global Burden of Disease report (GBD 2013 Risk Factors Collaborators 2015).

In addition to the direct food consumption channel, human health can also be negatively affected by the environmentally-mediated impacts of food production. For example, 20 per cent of premature mortality due to air pollution is derived from agricultural activities and biomass burning. Clearing forests for agriculture adds another 5 per cent to these mortality figures (Lelieveld *et al.* 2015). Highly hazardous pesticide use is still widespread across the globe, contributing to a range of health problems such as reduced fertility of male farm workers (Aktar *et al.* 2009; Roeleveld and Bretveld 2008) and increased incidence of fetal conditions and perinatal death (e.g. Maertens 2017; Regidor *et al*. 2004; Taha and Gray. 1993). Negatu *et al.* (2017) found that the expansion of commercial farming in the last decade in Ethiopia has led to a 6- to 13-fold increase in the use of pesticides, which has had an adverse impact on the respiratory health of workers exposed to these pesticides. In Argentina, recent evidence suggests that herbicides (including glyphosate, adjuvants and the metabolite AMPA) have teratogenic and genotoxic effects on mammals and humans and are linked to diverse pathologies and diseases (e.g. Beuret *et al.* 2005; Avila-Vazquez *et al.* 2017).

Importantly, increasing crop production has not guaranteed increased food security or even availability of nutritious food (Smith 2013). Currently, almost one fourth of total food production is wasted, an amount that could feed four times the number of the hungry people in the world (FAO 2011). Food waste is not just an issue linked to inefficiency; it raises important questions of equity and ethics in the global food system. This is especially problematic in countries where subsistence farming was replaced by intensified commercial farming. For example, Sierra Leone now exports food while people experience hunger locally (IFPRI *et al.* 2012). The food justice movement has also pointed out that women farmers and other marginal groups continue to experience land insecurity and lack of access to production resources. The case study presented in **Box 2.2** highlights the increasingly interconnected and systemic nature of a "wicked problem" and the converging issues that support and hinder socio-ecological resilience in agricultural landscapes.

Box 2.2 Case study: The complex reality faced by smallholders farming riverside vegetables in the dry season, Northern Ghana

In the semi-arid Guinea-Savannah zone of Upper West and East region of Northern Ghana, smallholders frequently have to contend with weather fluctuations, climate extremes (Tall *et al.* 2014), and hazards such as flooding, drought and storms (Lopez-Marrero 2010; Barrett 2013). All of these factors present risks to agriculture (Harvey *et al.* 2014), such as failed food and seed stores, crop loss, and infrastructural damage. The region is home to the nation's highest rural population of predominantly Dagaare and Fare-Fare agro-pastoralists (84 per cent in the Upper West) - 28 per cent higher than the rural average of 56 per cent and 8 per cent higher than the national average (FAO 2008). However, the current speed and magnitude of climate change undermines farmers' ability to employ traditional methods to cope with variability (Harvey *et al.* 2014; IFAD 2015). Their vulnerability is exacerbated by the fact that these farmers, like many other smallholders, tend to live in marginal environments (e.g., river banks, slopes or close to industrial lands); depend mostly on rain-fed agriculture; farm small parcels of land; and often lack risk mitigation tools, such as regulated long-term credit, cash reserves, reliable weather forecasts, early warning systems, farming inputs or storage infrastructure. Non-climatic stressors compound this risk, including market price fluctuation, under- or over-utilization of synthetic pesticides and fertilizers, and lack of information about appropriate application of inputs. Other issues include limited availability of organic inputs to boost soil fertility, increasing scarcity of land associated with population growth, and lack of labour due to worker migration to Southern urban centres (Tall *et al.* 2014).

Vulnerability is particularly high during the dry season, which typically runs from November – April, when cereal production comes to a halt due to the lack of rainfall, food stocks run low and demand for labour in the south is high (Laube *et al.* 2012). Many agricultural producers "sit idle" during this time, but in recent years, vegetable cultivation has increasingly become an important rural activity (including cultivation of chilli pepper, onion, garden egg, tomato, okra, cabbage, and sweet potato). Vegetables are space efficient, commonly intercropped with other staples crops like cassava, mango and banana, have a high nutritional value and cash crop value, and are growing in demand in urban and rural areas (James *et al*. 2010; Cernansky 2015). Dry season vegetable farming supports biodiversity in terms of landscape configuration and land management (Norfolk *et al.* 2013). Many farmers maintain the landscape surrounding the area in cultivation with patches of native trees, thereby increasing species diversity and heterogeneity as compared to monocropped landscapes (Fernandes and Nair 1986). Land management decisions can also benefit on-farm biodiversity. For example, farmers use mulch to retain soil moisture and promote decomposition, which in turn supports below-ground microbial communities. Concurrently, biodiversity benefits dry season vegetable farming. That is, trees surrounding farms house populations of birds and insects, which in turn support crop productivity through pollination and seed dispersal (Jha and Vandermeer 2010). Biodiversity around farms further provide provisioning ecosystem services such as medicinal and aromatic plants and fodder (James *et al.* 2010).

Despite these benefits, expanding dry season vegetable cultivation faces challenges. Current methods of irrigation are labour and time intensive – with farmers spending 4.5 hours per day filling up to 350 handheld buckets to collect water from riverbanks. The river water is reportedly contaminated, given multiple use requirements for washing, limited sanitation, livestock and the influence of upstream dams on turbidity and velocity. Labour productivity is hindered by limited health services, the continued presence of the parasite *Dracunculus medinensis* (guinea worm), and poor filtration and monitoring of water quality. External international drivers, e.g. European agricultural subsidies, are reducing the export markets for smallholder farmers (Laube *et al.* 2012). Concurrently, farmers suggest that changing climatic conditions they have observed, such as higher temperatures and humidity, have strongly influenced pest incidence on crop production (NPAS 2012). Thorn et al. (forthcoming) confirmed this, showing that in hotter, drier climatic conditions, the proportional abundance of ground- and vegetation-dwelling *Hemiptera* increases, particularly the economically damaging Phytophage, *Homoptera auchenorrhyncha cicadellidae,* and there is a greater risk of seed predation due to the presence of more granivores. However, the same factors have led to an observed greater abundance of long-tongued pollinators, from which farmers may benefit due to more efficient pollen dispersal and decomposition.

This case study highlights the increasingly interconnected converging issues that support and hinder socio-ecological resilience in agricultural landscapes. This complexity creates challenges in how best to balance needs in a changing climate. The need for more clarity is evident in current disagreements in national Ghanaian institutions, some of which advocate for more cultivation of vegetables, while others argue against it. To understand what interventions may enhance smallholder adaptive capacity and sustainability of crop production for environmental services, biodiversity and food security, a systems approach that analyses the interrelations between human and non-human systems across temporal and spatial scales is needed. The TEEBAgriFood Evaluation Framework can help by identifying the total range of impacts and externalities for vegetable cultivation in this scenario, helping the actors involved to choose the best-suited means of crop production for these specific circumstances.

2.2.2 The many dimensions of the eco-agri-food system create complex analytical and policy challenges

The eco-agri-food system is dynamic, complex and *multifunctional,* referring to the inescapable interconnectedness of agriculture's different roles and functions (IAASTD 2009). The concept of multifunctionality recognizes agriculture as a multi-output activity producing not only products (including food, feed, fibres, agrofuels, medicinal products and ornamentals), but also human health effects, livelihoods and employment opportunities, environmental services, landscape amenities, and a source of cultural heritages (IAASTD 2009; Robertson *et al.* 2014). An important attribute that underpins agriculture's multifunctionality is biodiversity. Agricultural biodiversity is a key component of farming systems and breeding systems worldwide, and results in nutritious foods that are culturally acceptable and often adapted to local and low-input agricultural systems (see, for example, **Box 2.3**). Biodiversity is also a source of important traits for breeding climate-tolerant, nutritious crops and animal breeds in the future (Bioversity International 2017). This central role of farm and landscape diversification in transforming agricultural and food system has been highlighted in the 2016 International Panel of Experts on Sustainable Food Systems report (IPES-Food 2016).

The multiple dimensions of the eco-agri-food system create complex analytical and policy challenges (EEA 2017). Efforts to alter one aspect of the system (e.g. reducing environmental pressures) will very likely produce impacts elsewhere (e.g. affecting employment, investments and earnings). This can also mean that interventions produce significant unexpected feedback and side effects. In addition, food systems do not operate in isolation from other systems such as those involving energy, mobility, and wider society, which in turn shape the context in which the food system operates. The use of simplified indicators (i.e. productivity per hectare or GDP of the agricultural sector), focused on selected measurable variables, can lead to poor decisions (i.e. increase the amount of pesticides) (EEA, 2017). Drawing from reviews of empirical evidence, the case studies presented in **Box 2.4** (Argentina), **Box 2.5** (Malawi) and **Box 2.6** (India) demonstrate how agricultural policies affected the many interconnected aspects of economy and society.

Agricultural policy, through its effect on price and availability of food, is known to be an important determinant of health (Pekka *et al.* 2002; Zatonski and Willett 2005; Birt 2007; Jackson *et al.* 2009; Hawkesworth *et al.* 2010; Wallinga 2010; Nugent 2011). However, health has largely been left out of consideration in agricultural policies (Dorward and Dangour 2012; Fields 2004; Hawkesworth *et al.* 2010), and tension between agricultural and nutritional/health policies is commonplace, and not only in the EU (Aguirre *et al.* 2015; Popkin 2011). The 2013 European Common Agricultural Policy reform liberalized the EU sugar market in 2017, abolishing sugar quotas and lowering EU commodity (or wholesale) sugar prices significantly. Scholars and public health research centres had projected that these changes would have the potential to increase sugar consumption (UKCRC-CEDAR 2015), particularly among the lowest socioeconomic groups (Aguirre *et al.* 2015), while causing substantial losses in sugar exporting by African, Caribbean and Pacific countries (Richardson 2009).

Policies that seem reasonable in one sector or for providing a solution to one problem can cause unintended adverse effects on other sectors, or over a longer time horizon or larger spatial scale. For example, in the Nagchu Prefecture of Tibetan Autonomous Region in China, the enforcement of a conservation area with the aim to restore degraded habitat has resulted in the eviction of semi-nomadic pastoralists who have depended for centuries on the land for grazing livestock, with adverse impacts on their livelihoods (Yeh *et al.* 2015).

Encouragement of high-efficiency irrigation can directly reduce the water use per area and the total water use of a given system. However, the reduction of existing costs of purchasing or pumping water affect the economic productivity of water, which can lead to other changes. First, crops that were previously unprofitable or even agronomically unfeasible may become lucrative, increasing the share of water-intensive crops in the overall cropping system, and increasing the average water use per area. Secondly, the overall area planted with crops may expand.

This increase in planted area can again lead to an increase in global water use. These system responses to improved technology can create rebound effects, where gains in efficiency are offset by expanded use. In some cases, global consumption may increase overall, in what is known as the Jevons Paradox. The extent to which a system rebounds will depend in large part upon the strength of system feedbacks (the balancing loops) and the new equilibria they create – at what point increased water and pumping costs inhibit further intensification, or depressed prices inhibit further expansion.

These examples show that systems thinking is needed to improve evaluation and impact assessment before policies or technologies are put in place. An analytical framework capable of integrating subsystems and showing connections between them will improve our understanding of the consequences of choices in quantitative and qualitative terms, across the whole eco-agri-food system. This framework will furthermore help to gather the information needed to make better decisions by agents involved across the value chain. Without systems thinking, we will continue to fail to consider the "what ifs". For example, in any theoretical scenario, what would have been the impact of investing in infrastructure, irrigation, extension and research had the government not spent most of its agricultural support budget on subsidies? What would have been the overall societal impact if more government resources had been used to implement ecosystem-based approaches, instead of agro-chemical input subsidies?

Ideology and culture affect how we understand issues around food (Rosin *et al.*, 2012a, 2012b). Food is a vital part of community, family and tradition, and encompasses many non-economic dimensions that are important for individuals and society, but it is often evaluated as just another thing to be bought and sold (Rosin *et al.* 2012a; Vivero-Pol 2017). Pretty (2012) called for developing new alternative models of agricultural and food systems that are culturally embedded and meaningful. Such models would put food at the centre of economies and societies, and ensure that food is produced in ways that improve the environmental systems of the planet.

Box 2.3 Case study: Genetic diversity and the eco-agri-food system

An essential component of the global eco-agri-food system is the genetic diversity of crops and livestock. These genetic resources, including both the diversity of cultivated varieties as well as the wild relatives of crops ("crop wild relatives") and livestock, are a key form of natural capital, and the conservation and use of agrobiodiversity is essential for the development of a more sustainable and resilient global food system.
In a way, the improved crops we grow are supported by the entire "genepool" of cultivated and wild diversity to which we can turn to mitigate pest epidemics and stressors like climate change through the breeding of new crop varieties. However, the development of improved varieties has at the same time led to a narrowing of crop diversity as farmers abandon traditional varieties, and as wild lands containing crop wild relatives are cleared for development. Without considering the important role of genetic diversity within the eco-agri-food system, we run the risk of disaster.

Nowhere are the dangers of low genetic diversity more pronounced than in the case of the banana, where a single, clonal variety dominates production for the global export market: the Cavendish. Similar to the Gros Michel, an older variety that was almost completely wiped out by a fungus known as the Panama disease (or Fusarium wilt), the Cavendish is currently facing a new fungal disease, Black Sigatoka (Pseudocercospora fijiensis), in addition to a mutated new strain of Fusarium wilt. Currently, banana plantations are sprayed with fungicides up to 45 times on an annual basis (Vargas 2006) at great economic and environmental cost. The wild relatives of the cultivated banana are a valuable source of resistance genes, and have been used to breed cultivars resistant to Black Sigatoka (Wu *et al.* 2016). However, wild banana populations are declining due to the direct and indirect effects of climate change (Emshwiller *et al.* 2015).

To ensure the long-term viability of banana production, crop diversity needs to be maintained. As this is costly and a global public good, the most adequate strategy is to manage on a global scale, through collaboration between countries. This requires that governments invest in conserving crop varieties in genebanks (and in farmers' fields) as well as crop wild relatives in their natural habitats, work to reduce further loss of agricultural diversity, and facilitate the use of these genetic resources. An example of how this can be partially accomplished is the International Musa Germplasm Transit Centre (ITC), home to the world's largest collection of banana varieties, both cultivated and wild. The ITC has distributed thousands of banana samples over the past 30 years to users in more than 100 countries, as its holdings fall under the jurisdiction of the Multilateral System of the International Treaty on Plant Genetic Resources for Food and Agriculture, which was adopted in 2001 and currently includes more than 100 participating countries.

Similar initiatives are undertaken for other crops; notwithstanding, the challenge of eroding genetic diversity remains huge and is exacerbated by the increasing industrialization of agricultural systems (IPES-Food 2016).

Box 2.4 Case study: What constitutes a "successful" model? The case of soybean industrial production in Argentina

In the last three decades, export-driven industrialized farming was promoted by the Argentinian government as the main model of production and as an agricultural development strategy especially in regard to GM soybeans (Pengue 2005; Teubal *et al.* 2008; Delvenne *et al.* 2013; Leguizamón 2014a; b; Torrado 2016). Favourable international market forces and globalization further aided this trend (Harvey 2003, Pengue 2005; Leguizamón 2014a; Cáceres 2015). This neo-extractivist developmental model (Gudynas 2009; 2014) is heavily dependent on modern technologies and inputs in monoculture-dominated large-scale production systems, as well as the extraction of natural resources (Pengue 2005; Teubal 2006; Cáceres 2015).

However, on what terms is the "success" demonstrated in this case understood? Argentina's industrial agriculture model could be understood as successful within the scope of neoliberalism, and as regards a few "winners", namely, large-scale farming and agribusiness corporations. Argentina ranks third in the world in the production and export of GM soybeans with ca. 20 million hectares under production and an output of 56 million metric tons during the 2014/15 season (Torrado 2016). Soybean has become the most important crop in Argentina (Pengue 2005; Aizen *et al.* 2009; Cáceres 2015; Leguizamón 2016; Torrado 2016; Lapegna 2017), with record harvests and profits (Leguizamón 2014a, 2016; Lapegna 2017). The government also benefited tremendously from resulting export tax revenues (Leguizamón 2014a, 2016; Torrado 2016; Lapegna 2017).

However, the benefits of this model become less certain (or negative) when other perspectives and criteria are considered. A large body of studies has documented that neoliberal policies supporting the expansion of industrial agriculture have generated negative environmental and social impacts. Social inequity is clearly evidenced. For instance, the country is producing "food" for over 300 million people but more than 30 per cent of its population (40 million people) lives below national poverty line (García Guerreiro and Wahren 2016). Moreover, industrial agriculture is one of the main drivers of land use change (Zak *et al.* 2004; 2008; Gasparri and de Walroux 2015); displacement of other crops important for domestic consumption (Teubal *et al*. 2005; Aizen *et al*. 2009); deforestation and forest fragmentation (Torrella *et al.* 2011; 2013; Hoyos *et al*. 2013; Piquer-Rodríguez *et al*. 2015); fresh water pollution (Pizarro *et al.* 2016a, b); and reduction of native plant populations and appearance of invasive species (Vila-Aiub *et al*. 2008; Binimelis *et al.* 2009; Martínez-Ghersa 2011; Ferreira *et al.* 2017). As a result of forest loss, production of vital resources such as wood, grass and hay for domestic animals, honey, and fibres have been considerably reduced (Trillo *et al.* 2010; Arias Toledo *et al.* 2014; Leguizamón 2014a), creating substantial negative impacts on subsistence farmers and indigenous people (Cáceres 2015; Leguizamón 2016; Cabrol and Cáceres 2017; Lapegna 2017). In the land rush for industrial crop cultivation (e.g. soybean), violence against indigenous and peasant families for land control escalated (Carrizo and Berger 2012; 2014; Arancibia 2013; Lapegna 2013, 2017; Leguizamón 2014a; b; Berger and Carrizo 2016).

Studies have also documented the negative social-ecological impacts of fumigation, particularly with glyphosate. Even though glyphosate is considered a less toxic alternative for weed control than some of its precursors, its use is controversial as there is increasing evidence of possible profound eco-toxicological effects of this herbicide on the eco-agri-food system (Bourguet and Guillemaud 2016; Cuhra *et al.* 2016). For example, there have been recent reports in Argentina of direct negative glyphosate effects on freshwater phytoplankton, bacterioplankton and periphyton (Peruzzo *et al.* 2008; Vera *et al*. 2010; Pizarro *et al*. 2016a; b); soils, microorganisms and fungi (Druille *et al.* 2013; 2016; Okada *et al.* 2016); invertebrates (Casabé *et al.* 2007; Mugni *et al.* 2011), amphibians (Lajmanovich *et al*. 2003; 2017; Attademo *et al.* 2014; Mariel *et al.* 2014); reptiles (Burella *et al.* 2017) and fish (Ballesteros *et al.* 2017a; b; Bonansea *et al.* 2017). In wild mammals, domestic mammals and humans, recent evidence indicates that the herbicide glyphosate (with adjuvants and the metabolite AMPA) has teratogenic and genotoxic effects and shows associations with diverse pathologies and diseases (Beuret *et al.* 2005; Carrizo and Berger 2012; 2014; Arancibia 2013; Avila-Vazquez *et al.* 2017).

Looking across the multiple tradeoffs derived from the model, Leguizamón (2014a; 2014b; 2016) pointed out a fundamental conflict between the narrative of "success" of the Argentinean GM soybean boom and socio-ecological sustainability. Systemic analysis is needed to evaluate alternative models of the eco-agri-food system, providing a comprehensive picture of performance, while considering different economic, environmental, health, and social indicators.

Box 2.5 Case study: Evaluating the impact of fertilizer subsidy policy in Malawi

This case study presents a review of the empirical evidence regarding the impact of an inorganic fertilizer input subsidy program implemented in Malawi between 2005 and 2010. Smallholder farmers dominate agriculture in Malawi and about 70 per cent of the population depends on agriculture for their livelihood, with maize being the major crop (Denning *et al*. 2009). Traditionally, most farmers used little or no inorganic fertilizers due to high costs. Also, before the intervention maize yield response to inorganic fertilizer was low, due to low soil organic matter and poor response of traditional varieties (Ngwira *et al.* 2012). Due to variable maize prices on the market, the purchase of fertilizer input was seen as risky and unattractive (Dorward and Chirwa 2011).

Starting in the 2005/06 growing season, the Malawian government implemented an ambitious program countrywide, which offered subsidized fertilizer and improved maize seeds through a voucher system, with vouchers distributed through district traditional authorities.

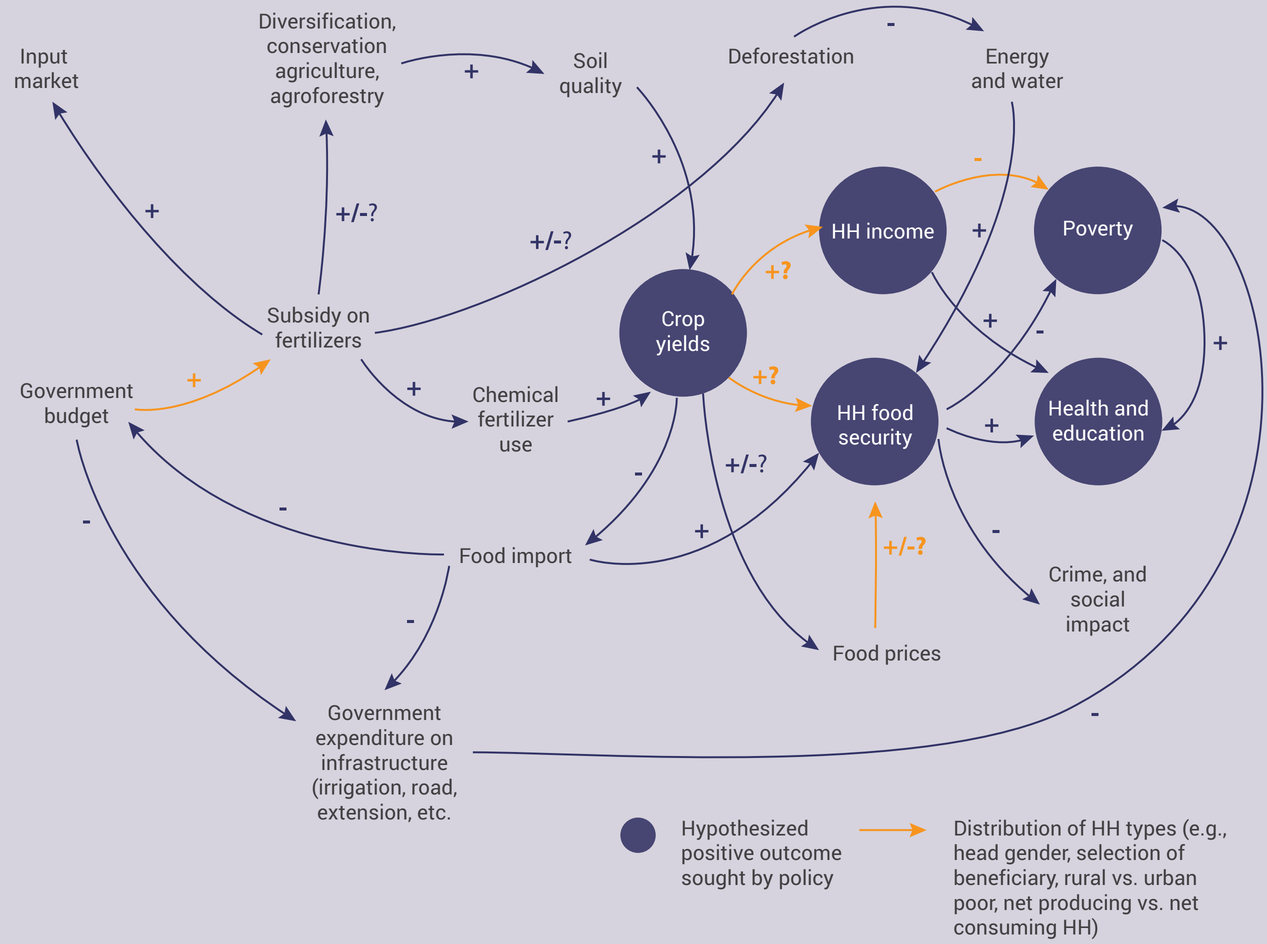
Despite some questions regarding specific figures, there is a consensus that the subsidy program increased agricultural productivity, with bumper harvests in 2005/06 and 2006/07. While this enhanced food security for individual households, the overall impact was uneven. As Sibande *et al.* (2015) found, only the richest 40 per cent of participating households achieved food security as a result of the subsidy programs, with 60 per cent remaining food insecure. It was also found that male-headed households were more likely to be food sufficient compared to female-headed households (Dorward and Chirwa 2011). This gendered effect was partly due to the fact that land ownership was a requirement for participation. In a survey by Holden and Lunduka (2013), 40 per cent of sampled households reported a positive effect on their children's health, with another 65 per cent indicating that children's school attendance improved. However, Lunduka *et al.* (2013)'s review study suggested that the subsidy program might not have improved the overall food security. While national poverty rates decreased by 2.7 per cent, it was mostly the urban poor who benefited from lower food prices (Arndt *et al*. 2016).

At their peak in 2008/09, subsidy costs accounted for 80 per cent of the public budget to agriculture and 16 per cent of the total national budget (Dorward and Chirwa 2011). This had effects on other areas, with reduced budget allocated to infrastructures such as roads and irrigation, as well as to extension and research (Arndt *et al.* 2016).

Importantly, the various studies, which sometimes reached contradictory conclusions (indicated by the "+/-" sign in **Figure 2.1**), show that the impact of such a vast subsidy program is often difficult to assess and quantify (indicated by question marks). This is partly due to differences in timing and methods of data collection. Even when the intended outcome is observed, distributional effects may or may not be positive (the yellow triangle sign in the Figure indicates where such distributional effects may rise). A subsidy program as broad as this one has impacts beyond agricultural practices and food supply. It can improve children's health and school attendance, for instance. Yet, the impact is often heterogeneous, e.g. unevenly divided in terms of benefits between male- and female-headed households, rich and poor households, or urban and rural households. Such a program may inadvertently reinforce existing inequalities. The interdependencies in an eco-agri-food system are complex and trade-offs need to be carefully weighed.

One interesting question is whether redirecting government budgets from simply providing inorganic fertilizer to alternative approaches that are focused more on ecosystem functions and sustainable land management would have helped to avoid some of the documented unintended negative effects while improving productivity in the long run, and what other unanticipated changes might emerge. Uptake of such techniques remains low in Malawi, and outcomes for food security and income are mixed. But their appeal may grow if external driving forces such as climate change put even more pressure on energy supply and crop yields.

Figure 2.1 Mapping evidence of policy impact (Source: authors)



Box 2.6 Case study: Energy subsidy and groundwater extraction for irrigation in India

Groundwater irrigation in India covers more than 86 million hectares (ha) out of 192 million ha of gross cropland (GoI 2013). However, agriculture in India is trapped in a complex cycle of groundwater depletion and dependence on energy subsidies (Shah *et al.* 2008). The government subsidizes electricity costs for pumping ground water to encourage greater agricultural productivity, which has encouraged farmers to continue drilling deeper and pumping more. The subsidies are often priced at a flat tariff, if at all, and the groundwater is seldom effectively regulated. As a result, farmers lack monetary incentives to save water or use it efficiently (Narayanamoorthy 2004). The resulting crisis in groundwater resources, especially in northwestern India (Rodell *et al.* 2009), had ripple effects on smallholder farmers, rural communities, and the environment. Despite effort by the government to formulate groundwater regulations and pass state laws, enforcement has largely been ineffective.

Systems thinking is useful for looking at the impact of energy subsidies in India. For instance, several feedback loops exist between the energy subsidies, national imperatives for economic development, food security, the overexploitation of groundwater and consequences for rural livelihoods. At the political-institutional level, energy subsidies have threatened the viability of State Electricity Boards: their capacity is physically stretched by irrigation pumping, and their capacity as organizations is undermined as there are limited incentives for efficiency. Energy subsidies have affected rural populist politics in that political efforts to regulate water are hindered. Proliferation of pumps has also jeopardized the power supply in several states, with implications for regional and urban power services. The energy subsidies have also incentivized farmers to choose water-intensive crops such as rice over less demanding ones, which reinforce the rising demand for irrigation water.

Many responses have arisen in the wake of the socio-ecological challenges associated with energy subsidies in agriculture in India. Most of these include various groundwater management proposals. Some, like the strategy implemented in West Bengal, involve virtually no subsidy on power, because the state has metered all its tubewells and the government now charges farmers at near-commercial rates (Shah *et al.* 2012). Other regions have focused on finding a second-best middle ground that fits the realities of the state level political economy and physical conditions. One such effort is the *Jyotigram* scheme introduced in Gujarat which charges farmers a flat rate tariff, while imposing explicit rationing of high-quality power (Shah *et al.* 2012). Some are focused on improving irrigation efficiency and transitioning away from flood irrigation (Fishman *et al*. 2015). Others have focused on the important role of collective action in order to restrict highly water-consumptive crops where state capacity to control groundwater use is limited (Meinzen-Dick *et al.* 2016). Whether the effort is aimed at correcting distortions rooted in the economic or human behaviour domain, a systems view is necessary to ensure that we look beyond the immediate steps or consequences and consider broader scales and dynamics.

2.2.3 Conceptualizing a sensible operating space for the eco-agri-food system

How can the overall viability and sustainability of any eco-agri-food system be assessed? Much of the current research that attempts to look beyond simple productivity as the only meaningful measure of agricultural production has focused on the biophysical impacts of production systems on the environment. Many studies look at how to close the 'yield gap' (i.e. raise yields in less productive systems vis-a-vis industrial agriculture) (Harvey *et al.* 2014; Campbell *et al.* 2014) by examining the impact of conservation strategies on agricultural productivity (Branca *et al.* 2012). It is widely accepted that for human activities to be sustainable, we must respect the ecological constraints on what we can do on and with planet Earth (Clift *et al.* 2017).

Rockström *et al.* (2009a; 2009b) defined 'safe operating space for humanity' in terms of a set of Planetary Boundaries, which has significantly influenced the international discourse on global sustainability (Dearing *et al.* 2014) by using nine interlinked biophysical (hereafter referred to as ecological) boundaries at the planetary scale that global society should remain within, if it is to avoid "disastrous consequences for humanity". Raworth (2012)'s extension of the Planetary Boundary concept to include social objectives, such as health, gender equality, social equality, and jobs, in the context of sustainability policy and practice has produced a heuristic with an explicit focus on the social justice requirements underpinning sustainability (see **Figure 2.2**) (Raworth 2012). Raworth's approach brings planetary boundaries together with social boundaries, creating a safe and just space between the two, in which humanity can thrive. The concept of "safe and just operating spaces" has since been used to guide analysis of regional social-ecological systems in a variety of situations and contexts (for example, in China by Dearing *et al.* (2014), and in coastal Bangladesh as described in **Box 2.7**).

On the one hand, the eco-agri-food system, which is bounded by the same overarching (global) ecological and biophysical constraints and shares the same social foundations as human development, must operate within a "safe and just space for humanity". Defining this space for a given system obviously depends on the values and worldviews held, but systems thinking can play a role fostering conceptualization and cultural narratives that better appreciate the social and natural foundations of sustainability. On the other hand, the performance of eco-agri-food systems plays a critical role in determining if humanity can thrive within planetary and social boundaries. Systems thinking again can offer conceptual guidance on the methodologies of analysis and governance.

Figure 2.2 The safe and just space for humanity. (Source: adapted from Raworth 2012)

Box 2.7 Case study: Sustainability of coastal agriculture in Bangladesh: Operationalising safe operating space using social-ecological system dynamics

The safe operating space concept offers a new basis for negotiating trade-offs for sustainable development in the face of growing challenges. Using the safe operating space concept to evaluate the complex dynamics (e.g. feedbacks, nonlinearity) of social-ecological systems, in this case, of agriculture in coastal Bangladesh, involved three research steps: 1) analysis and understanding of the co-evolution (drivers, trends, changes points, slow and fast variables) of social-ecological systems involved (Hossain *et al*. 2015; 2016a), 2) unravelling the dynamic relationships (e.g. interactions, feedbacks and nonlinearity) between social and ecological systems (Hossain *et al.* 2016b), and 3) simulation and exploration of the social-ecological system dynamics by generating eight 'what if' scenarios based on well-known challenges (e.g. climate change) and current policy debates (e.g. subsidy withdrawal) (Hossain *et al.* 2017).

Coastal agricultural production doubled in Bangladesh (1.5–3.0 Mt) from 1972 to 2010 due to technological innovation and fertilizer input. The ecosystem, however, has degraded since the 1980s due to increasing temperatures and salinity levels (in both soil and water), rising sea levels and rising ground water levels (Hossain *et al.* 2015, Hossain *et al.* 2016a). Recorded statistics confirm that this area is one of the most vulnerable to climate change (Maplecroft 2010; Ahmed *et al.* 1999) and is also under stress because of land use change, water scarcity, floods, salinity rise and urbanization (Hossain *et al.* 2015; ADB 2005). Projections show that the detrimental effects of climate change in the area are likely to continue, as rice and wheat yields decrease due to temperature increases (MoEF Bangladesh 2005). In such a context, it is highly important to know the proximity of the social-ecological system to tipping points and the chances of stepping outside the safe operating space if a 'perfect storm' of social-ecological failings is to be avoided.

Prior to employing system dynamic modelling to explore the safe operating space in the Bangladeshi delta, we defined the safe operating space in relation to the envelope of variability, environmental limit and impacts on society, assuming that, outside the envelope of variability for crop production, income and GDP, the society will move out from the safe operating space, posing danger to humanity. Eight 'what if' scenarios were formulated based on well-known challenges, current policy debates and stakeholder consultations on the Bangladesh delta in relation to issues such as climate change (debate of 2°C and 3.5°C temperature rise in Paris agreement), sea level rise, withdrawal of subsidy according to World Trade Organization by 2023 and withdrawal of water in the upstream of Ganges delta. Model simulation results for the period 2010s to 2060s revealed that a 3.5°C temperature increase over the period would be dangerous for the social-ecological systems, especially when combined with sea level rise, withdrawal of water and withdrawal of subsidies. Based on the simulated results, we suggest that agricultural development in Bangladesh can stay within the safe operating space by managing feedback (e.g. by reducing production costs) and the "slow" biophysical variables (e.g. by remaining below a 2°C temperature increase), and revising national policies regarding agricultural subsidies. This case study highlights the value of modelling complex social-ecological systems in data scarce regions and demonstrates how we can operationalise sustainability science concepts (e.g. tipping points, limits to adaptation) in real world social-ecological systems.

2.2.4 Currently applied conceptualisations and analytical tools are limiting

'Silo analysis' not only limits a comprehensive understanding of the interconnected nature of the eco-agri-food system, but is also a consequence of the limited availability of data and means to investigate the eco-agri-food system as an integrated complex whole. In this section, we provide some examples of the limitations of the currently applied conceptualizations and analytical tools, which contributed in part to today's challenges with regard to the eco-agri-food system. We also highlight how synergies and coherence can be gained when evidence is generated using concepts and methods that are aligned with systems thinking (Tallis *et al*. 2017).

Treating natural capital using the tools of national income accounting

To understand the limitations of current approaches to assessing the value of natural capital, it is helpful to understand the origins of these approaches. The current system of economic accounting was developed in the 1930s, particularly in the U.S. and U.K. with the creation of the concept of Gross National Product (GNP). GNP was cast as a way to understand "return on investment" that depended on maintaining capital stocks (Solow 1956). This enabled the macro economy to be analysed as if it were one big firm. An important impact of this conceptual development was that it redirected the concerns of economic theory and economic policies away from questions of income distribution towards production, especially through improving efficiency and ensuring the optimal allocation of productive inputs. When employed for long enough, indicators like GNP can ultimately change underlying perceptions of values, becoming valued attributes in their own right (Haider *et al.* 2015), (see the earlier Argentinian case study in **Box 2.1**). Although indicators are formulated to measure what we value, in practice the opposite often happens – we come to value what we measure (Meadows 1998).

An important advancement in income accounting was the realization that capital stock should include the contribution of the services of nature ('natural capital') (Dasgupta and Mäler 2000). In 2012, nearly a century after the rise of GNP as a metric, the UN established the System of Environmental Economic Accounting - Experimental Ecosystem Accounting (SEEA-EEA) (UN *et al.* 2014). Alongside it emerged the concepts of 'green accounting' (Serafy 1996) and 'inclusive wealth' (UNU-IHDP and UNEP 2014).

The *Inclusive Wealth Report* describes four kinds of capital: manufactured or physical, natural, human, and social (UNU-IHDP and UNEP 2014). Each of these capitals is involved in agriculture and all are linked in complex ways. For example, while it may be technologically possible to replace human capital (e.g. farm workers) with manufactured capital (e.g. machinery), this may have negative consequences on social capital (e.g., social networks). As Daly (1996) pointed out, the notion of 'capital' implies that one type of capital can be substituted by another type of capital, a viewpoint that has significant shortcomings. Indeed, the ultimate source of all manufactured capital is the natural world and its essential services are not substitutable.

Georgescu-Roegen (1984) argued that land, labour, and capital are *funds*, not stocks. Funds must be maintained by preserving the conditions that enable them to be perpetuated. Especially in the eco-agri-food system, this seems a more appropriate concept. Ecosystem services such as soil fertility and other vital soil characteristics must be maintained to sustain the output of crops in the long run. Labour (agricultural workers) must also be maintained through health care and the supporting institutions of family and communities. This way of thinking emphasizes the importance of social capital in the economic process. Social capital is particularly important in the eco-agri-food system, whose success depends directly on the supporting functions of family and community (e.g. via the provision of information or appropriate inputs, or labour sharing). Many aspects of industrial agriculture work against sustainability by undermining the social structure that supports farm workers (Lobao and Stofferahn 2008; Goldsmith and Martin 2006) and by drawing down the funds supporting ecosystems services like water quality and availability, pollination and pest control insects, and soil nutrient cycling (Kimbrell 2002).

Awareness is growing that a new way to capture interdependencies and assess trade-offs is required. As Imhoff (2015, p.5) writes in the report on a "Biosphere Smart Agriculture in a True Cost Economy":

> "*In the face of a rapidly overheating climate, collapsing fisheries, degraded soil, depleted water resources, vanishing species, and other challenges directly related to agriculture, we can no longer afford to pursue a flawed accounting system.*"

The Millennium Ecosystem Assessment (MA), The Economics of Ecosystems and Biodiversity (TEEB), and the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES) are known for their focus on the importance of ecosystems to human well-being and to economic activity. These efforts document the importance of natural capital to economic activity, and the cost of environmental degradation on society. Yet, in view of the magnitude of the continuing deterioration of many ecosystems and social institutions, we must take the concept of biodiversity and ecosystem services and the many dimensions of human wellbeing further by looking at how these issues might be addressed. One of the most salient problems is the difficulty of operationalizing the broad vision of these initiatives; that is, incorporating complexity and interdependence in a systems approach. Because the dependencies and impacts are indirect, interconnected, and complex, seemingly reasonable sector-based policies can lead to unintended consequences that make the whole system (along with its stakeholders) worse off. A key step is to first broaden our analytical framework to allow for the conceptualization and evaluation of the far-reaching implications of various options to manage the eco-agri-food system, in order to inform decision-making, and to improve the existing standards and guidance (e.g. IFC Environmental and Social Safeguards, EIA and SEA directives of the EU).

Beyond single numeraires for evaluating multi-dimensional challenges

Over the past few decades environmental accounting has matured and standardized. Researchers across disciplines can now refer to a set of common methods to measure nature's services. However, like any accounting methodology, environmental accounting is based on simplifications of reality that affect which variables are included, the numbers produced, and their relevance. In the course of reaching consensus on how to construct natural resource accounts or how to estimate environmental services, conceptual difficulties have been glossed over or ignored entirely. Most importantly, in many empirical applications the ecosystem services narrative reduces the value of nature to merely monetary terms that can be quantified and brought into cost-benefit calculations.

Nature is perceived and valued in starkly different and often conflicting ways, and embracing such diversity can aid transformative practices aiming at sustainable futures (Pascual *et al*. 2017). In the context of eco-agri-food system, food has different meanings to different people, including, for example, calorie production, income generation, ways of living, and cultural heritage. Developed within the context of the IPBES, the inclusive valuation of nature's contributions to people (NCP) aims to improve decision making using a pluralistic approach to recognize the diversity of values (Pascual *et al.* 2017).

Appropriate indicators that reflect the complexity of the eco-agri-food system are needed. Haider *et al*. (2015) proposes four principles to guide researchers and practitioners when looking at complex systems. First, indicators are integral parts of a wider monitoring and management system and they provide the key tool by which different elements of the monitoring and evaluation process can be logically connected as attributes change over time. Second, indicators should be designed and used with a suite of other assessment tools and as a coherent part of a wider monitoring system. Even though the use of a single index can provide information (such as GDP), the complex nature of social-ecological systems means that such an index will never adequately capture measures of sustainability. On the other hand, many environmental monitoring programs combine various types of indicators into uncoordinated simple lists with little hierarchical or interactive structure (Gardner 2010). Indicators can only have relevance to management and decision-making processes within complex systems if they are used in coherent and interactive ways, and in the context of a particular aim or objective. Third, it is essential to understand how different indicators relate to the wider system that is being monitored. Finally, indicators, and the monitoring and management systems to which they are linked, should be designed through a participatory process that involves the key stakeholders who are responsible for or influenced by the system attributes that the sustainability indicators are trying to represent. Participatory approaches to monitoring sustainability are particularly important in developing countries, where engagement in the design and execution of monitoring programs by local stakeholders may empower them to better manage their own resources (Haider *et al.* 2015). Moreover, a participatory approach can also encourage a culture of learning, which is paramount to the success of adaptive management (Cundill and Fabricius 2009).

The limitations of comparative static approaches

"Comparative statics" provide a way to evaluate the effects of a change in policy or a production practice by using two 'snapshots', one before and one after a change, in order to assess its impact. However, there are limits to such comparative static analyses when dealing with dynamic and evolving systems. These types of comparisons are usually made based on the assumption that variables remain constant and will not change in a significant way in the future, i.e. the 'all other things being equal' principle. This assumption is highly problematic when considering complex adaptive systems, which are driven by emergence and characterized by change.

Moreover, a snapshot approach does not look at the dynamic interaction of elements within a system, so it may not be representative of the full effects of a change. Some interdependencies might be poorly captured and others overlooked because they are deemed irrelevant or because their effects only become apparent over the long-term.

The case of genetically modified organisms (GMOs) crops is instructive. As Hakimoct (2016) summarizes:

"*The promise of genetic modification was twofold: By making crops immune to the effects of weed killers and inherently resistant to many pests, they would grow so robustly that they would become indispensable to feeding the world's growing population, while also requiring fewer applications of sprayed pesticides.*"

These claims were based on several studies that seemed to convincingly show that GMOs increased yields, required fewer chemical inputs, and had no adverse effects on human health. GMOs were first allowed in the United States and Canada some 20 years ago, but were subsequently banned in most countries in Europe. These political choices led to an unintentional but useful controlled experiment assessing GMOs effect on production, biodiversity, and human and soil health, amongst other factors. According to Hakimoct (2016), the U.S. and Canada showed no discernible gain in crop yields per acre compared to Western Europe. Another unexpected outcome was that herbicide use increased in the U.S. By comparison, Europe's major producer, France, reduced its use of herbicides and pesticides during the same period. Other unexpected impacts emerged in the social sphere. In India, many studies have recognized the adverse social impacts of GMOs stemming from the inability of smallholder cotton farmers to repay loans, which leads to a loss of autonomy and control over food production. These effects have been associated with farmer suicides, the loss of crop genetic diversity and decline in the number of locally adapted varieties.

The debate about GMOs is not conclusive, in part due to a lack of long-term studies and comprehensive assessments of impacts on ecosystem services, social dynamics, and human health. For example, we lack an understanding of how GMOs affect the long-term evolution of herbicide and insecticide resistance in crops, impact predators and pollinators, affect irrigation needs and seed distribution policies, and how GMOs perform under variable precipitation (Romeu-Dalmau *et al.* 2015). To better understand the effect of GMOs, a systems approach would improve our understanding of the interdependencies and trade-offs involved, and thus the situations, contexts and conditions where GMOs would be appropriate or not.

The limitations of efficiency as policy objective

The goal of efficiency is a central concept in economic policy and in research to improve agricultural production. It is largely taken for granted that it is an objective criterion and not a value judgment. But as Bromley (1990) pointed out, efficiency is a value-laden ideology—part of a shared system of meaning and comprehension. It is not only an essential part of microeconomic theory, but also a driving force in market economies. Businesses strive to create their products at the lowest possible cost, arguably to avoid wasting scarce resources, but also by externalizing a number of costs linked to the environmental and social impact of their activities.

The picture from Tanzania in **Figure 2.4** shows the stark difference between plots planted in industrial monoculture versus smallholder agriculture (<0.5ha) (see **Figure 2.4**). Using measures of efficiency and profitability, the industrial system might look preferable, but what effects are left out? Taking a systems approach encourages policy makers to consider a larger spatial and temporal boundary, and to assess the impact of alternatives on a broader set of policy considerations, such as employment of smallholder farmers, destruction of the family farming-based system, loss of local knowledge, impact on bio-diverse multifunctional landscapes, and effects on connectivity, flood buffers, habitats, and personal relationships.

Figure 2.3 Photo showing industrial monoculture alongside of smallholder agriculture in Tanzania (Source: Bourne 2009)

As Bromley (1990) pointed out, efficiency is only one possible policy goal with no particular claim to being more important than any other. Efficiency is usually interpreted as 'allocative efficiency', i.e. focusing on allocating productive inputs among alternative uses in order to maximize output. However, this is only one way to define efficiency. In systems thinking the concept encompasses the efficiency of ecosystems functioning, or efficiency in the allocation and preservation of social capital to improve the well-being of society. It should also include the notion of 'adaptive efficiency'[2], where the focus is on practices and processes that will enable a system to adapt to changes. This is a core message from resilience thinking: prepare for the unexpected, for example through diversification, maintenance of redundant resources that can be mobilized quickly, and focusing on (social) learning through on-going experimentation (Folke *et al*. 2010; Walker and Salt 2012).

The limitations of marginal analysis and discounting

Marginal analysis is a key decision-making tool in many businesses. It is the process of identifying the relative benefits and costs of alternative decisions by examining the incremental change in revenue over costs caused by a one-unit change in inputs or outputs. The eco-agri-food system complex has significant implications for sustainability and equity, and limiting evaluations to the yardstick of 'value addition' does not address important equity and resilience issues (TEEB 2015). Marginal analysis does not capture the cumulative effects of small decisions. Kahn (1966) described the "tyranny of small decisions" as a situation where small, seemingly insignificant decisions accumulate and result in an undesirable long-run outcome. Such situations abound in environmental issues. For example, as noted by Odum (1982), the marshlands along the coast of Massachusetts and Connecticut in the U.S. were reduced by 50 per cent between 1950 and 1970 because of small incremental decisions made by landowners.

Discounting is another thorny issue in economic valuation and one that illustrates the divide between an individual perspective and the perspective of "human society" (Gowdy *et al*. 2010). Ecosystem services that support food production become more important as external inputs increase in cost or become scarcer. Even if individuals demonstrate preference for current over future benefits (i.e. discounting the future), that does not necessarily mean that this is appropriate for social decisions (Quiggin 2008). The question of which time frame to use is also critical. Scenario analysis of diverse plausible futures, established envisioned desirable and undesirable futures, and backcasting are approaches increasingly gaining traction as a planning approach to address possible future trajectories along varied time horizons over decadal periods. This diverts from traditional economic planning of four- to seven-year time horizons.

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[2] Defined by North (2010) as a society's effectiveness in creating institutions that are productive, stable, fair, and broadly accepted--and, importantly, flexible enough to be changed or replaced in response to political and economic feedback.

2.3 A SYSTEMS APPROACH FOR THE ECO-AGRI-FOOD SYSTEM

2.3.1 Origins and evolution of systems thinking

Systems Thinking (ST) is an approach that allows better understanding and forecasting of the outcomes of our decisions, across sectors, economic actors, over time and in space (Probst and Bassi 2014). It places emphasis on the system, made of several interconnected parts, rather than its individual parts. Originating from Systems Theory, ST is transdisciplinary, cutting across social, economic and environmental dimensions. Further, it aims at identifying and understanding the drivers of change as determined and impacted by feedback loops[3], delays and non-linear relationships.

ST supports the integration of information through the explicit representation of causal relations. It uses feedbacks, delays, and non-linearity, three crucial properties of real systems, to describe these relations (Sterman 2000). The strengths of some causal relations are determined, among other factors, by cultural norms. New causal relations may emerge in specific settings, requiring the application of a systems approach customized at the local level. To navigate through complexity, ST supports the identification of the main mechanisms underlying the performance of a system through the creation of a cognitive map, such as the Causal Loop Diagram (CLD), described in more detail in Section 2.3.4.

ST is general in scope, meaning it can be applied to several topics and types of systems, and focuses on the integration of drivers of change across fields. As a result, it builds on other applications of Systems Theory. Examples include systems biology, ecology, and systems engineering.

There are several methodologies and tools that support the implementation of ST. In general, the identification of the components of a system and of the relationships among these components represents the *soft* side of Systems Theory; attempts to quantify these linkages and forecast how their strength might change over time represents the *hard* side of the field (Probst and Bassi 2014).

Both applications have greatly evolved over time, originating from Wiener's (1948) book "Cybernetics" in the homonymous field, Odum's (1960) article titled "Ecological potential and analog circuits for the ecosystem", Forrester's (1961; 1969) publications on industrial and urban dynamics (respectively) in the field of System Dynamics, Lorenz's (1963) work on chaos theory, von Bertalanffy's (1968) work and book titled "General System Theory" in the context of biology, to cite a few examples.

Over time, advances have been made both in systems science (e.g. Complex Adaptive Systems, coined by the Santa Fe Institute) and applications of ST to public policymaking (e.g. The Limits to Growth, published by the Club of Rome (Meadows *et al*. 1972) and the subsequent expansion of the field of System Dynamics (see Chapter 7).

When seeking to implement ST, the soft side is characterized by seeking to understand and map system complexity. This is achieved through the creation of system maps, also called Causal Loop Diagrams (CLD), Bayesian networks (see **Box 2.8** for an example), and mind maps, to cite a few examples. These approaches, together with additional techniques to harvest expert opinion (e.g. Delphi Analysis), allow for the creation of a shared understanding of how a system works, which in turn helps to identify effective entry points for (human) intervention, such as public policies. When this is done using a participatory approach, it helps bring stakeholders together, creating the required building blocks for the co-creation of a shared and effective theory of change.

The hard side of ST is represented by several simulation methodologies and models, as presented in more depth in Chapter 7. These methodologies and models offer different ways of unpacking complexity (UNEP 2014). For instance, models can be bottom-up (e.g. Agent-Based Modelling, systems engineering models, Partial Equilibrium Models) or top-down (e.g. General Equilibrium Models, System Dynamics). Models may focus on the understanding of the behaviour of agents, and how these interact with one another, or on explaining the drivers of structural change in the system. Hybrid approaches also exist, where various models are integrated into nested models, or fully incorporated into an integrated model (Probst and Bassi 2014; UNEP 2011). Overall, we find that the modelling field is rapidly evolving, and there is increasing literature on complex systems and on approaches to tackle complexity. We believe that the TEEB Evaluation Framework, built on ST, can help in both: 1) identifying what should be included in modelling exercises, to provide useful inputs to decision making, and 2) determining what models to use (if in isolation or in conjunction with others) and, more importantly, how to interpret their results (according to their strengths and limitations).

In the current report, our perspective embraces the notion (and associated behaviours) of embeddedness within the dynamic flows and cycles of nature, and thereby supports

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[3] "Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts et al. 1983, p.16).

the analysis and understanding of a whole system rather than its parts or subsystems (Meadows 2008; Sterman 2000). Analysing the underlying structure of the system allows for plausible inferences about its past and future behaviour (Coyle 2000), which are useful for policy formulation and evaluation.

2.3.2 Applying systems thinking to the eco-agri-food system

TEEBAgriFood makes use of scientific advances in relevant disciplines, and argues for better integration of knowledge across sectors and actors. In addition, the study emphasizes the importance of sharing results of analysis effectively in order to better inform decision-making. We argue that using ST and related tools can help all actors in the eco-agri-food system to better plan for the future. Applications of ST can already be found in many other fields within both the private and public sector; together with an emphasis on Learning Organizations (Senge 1990) we can better understand how socioeconomic and ecological systems, as well as organizations and institutions, can learn and evolve over time. The TEEBAgriFood Evaluation Framework is inspired by ST and attempts to capture impacts of production, processing and distribution, and consumption throughout the system, keeping in mind of the drivers and contexts of the eco-agri-food system, and important properties of the system such as dynamics, scales, and feedbacks. By doing so, the Framework can help identifying what should be included in more comprehensive modelling approaches.

The eco-agri-food system involves many components, or subsystems, which interact dynamically and give rise to unpredictable properties that emerge at different levels of organization - so-called emergent properties - which are the essential reason for studying systems in the first place. We are accustomed to dealing with ***complicated systems***, composed of many different parts which interact linearly, and whose behaviour thus follows a precise logic and repeats itself in a patterned way. These complicated systems are therefore predictable. ***Complex systems*** are dominated by dynamics that are very difficult to predict. These dynamics are the result of multiple interactions between variables that do not always follow a regular pattern, and are driven by various feedback loops. As a result, their interplay can lead to unexpected consequences. The rapidly evolving environment in which we live requires responses based on careful analysis of alternative intervention options, especially when multiple and simultaneous challenges emerge. Decisions that do not consider the complex dynamics underlying the true causes of a problem risk unintended consequences or side effects.

Today's challenges are increasingly complex, and it will be necessary to apply systems thinking if we are to improve our abilities to address the challenges. In an analysis of the top 100 questions for global agriculture and food security, Pretty *et al.* (2010) identified a series of interlinked and overarching challenges for this century, grouped into: i) climate change and water, ii) biodiversity and ecosystem services, iii) energy and resilience, iv) social capital and gender, v) governance, power and policy making, vi) food supply chains, and vii) consumption patterns. They demonstrate the intertwining nature of agricultural and food systems, and show that solutions will have to come from more than one sphere of political, technological and economic life (Pretty *et al.* 2010; Pretty 2012).

An improved global food system requires radical change to its organization (Rosin *et al*. 2012a; IPES-Food 2016). In reviewing the literature of recommendations for reconfiguring the global food system, Rosin *et al.* (2012b) highlighted that the transformational recommendations all involve significant shifts in the structure and operation of the global food system. One example of structural change in the model of agriculture called upon by the International Panel of Experts on Sustainable Food Systems is to diversify farms and farming landscapes IPES-Food (2016). The environmental limits of our food-related activities must be respected; the functions of the ecosystems in which food is produced must be maintained; the multiple outputs of agriculture and its multiple roles must be considered. Take conservation for example. The aforementioned recommendation implies a recognition of the multiple and often non-monetary and cultural incentives for conservation in agricultural landscapes of different actors. Changes in food production systems must ensure that the environmental, social, and human health qualities inherent to food production and consumption, including but not limited to economic benefits, are valued and therefore maintained. A radical shift in our treatment of food is called for, both in terms of the values we attach to food, and in our imaginings of more just and flexible systems.

Using systems thinking requires a shift in fundamental beliefs and assumptions that constitute what are referred to as our 'worldviews'. These are essentially intellectual and moral foundations for the way we view and interpret reality. This in turn requires a shift in our beliefs about the nature of knowledge and the processes of knowing. For instance, when it comes to judgments about what constitutes improvements to the way land is farmed, our worldviews reflect our views on the nature of human values, particularly as they relate to ethics and aesthetics (Bawden 2005).

Complexity theorists have long recognized the importance of cultural narratives, what Sahlins (1996) refers to as "cosmologies." These are belief systems so ingrained in language and customs that they are hard to recognize. Researchers are making headway in applying the general principles of systems thinking to a variety of social problems involving sustainability (Newell *et* *al.* 2009; Dyball and Newell 2014), and are moving from focusing solely on individual behaviour to emphasizing the importance of cultural institutions and society's assumptions about which policies are feasible and which are not. Behavioural economists and psychologists have made progress in identifying patterns of individual behaviour relevant to policy formulation. Much more work remains in order to understand how transformation towards sustainability can be triggered and supported by policy at societal level.

Increasingly, various fields of policy and corporate practice recognize the necessity of ST and systems approaches in solving today's interconnected and complex challenges. For instance, the development community is moving toward more comprehensive—or systems level—thinking as it looks at issues of poverty, hunger, and malnutrition (Fan 2016). International development organizations such as UNDP, the World Bank, USAID, CIDA, and Japan International Cooperation Agency have shifted to systems concepts-based (FASID 2010), holistic, and integrated approaches (FHI 360 2016) for the design, delivery and evaluation of development programs. The conservation community is also moving in this direction. The Nature Conservancy (TNC), for example, recently stated that creating "systemic change" (creating or strengthening the social, economic, political, and cultural systems that comprise and sustain a socio-ecological system) should be the focus of interventions (TNC 2016). Furthermore, more cross-sector and cross-disciplinary initiatives are emerging, aiming to promote integrated approaches and collaborative work that breaks silos. Among them, the Bridge Collaborative (TNC 2017) envisions global health, development and environment communities jointly solving today's complex, interconnected challenges, first by recognizing the interconnectedness of the challenges each of the three communities face.

These examples show how ST is increasingly embraced because it takes a holistic view of the world and allows for the discovery of interactions (Röling and Jiggins 1998). While system science has been around for more than six decades, to meaningfully embrace the systems approach requires fundamental changes in the way we view and analyse problems and design solutions, as well as the type of institutions we create and use to do this. The TEEBAgriFood study offers a tool, in the form of an Evaluation Framework, to help us advance towards this type of change.

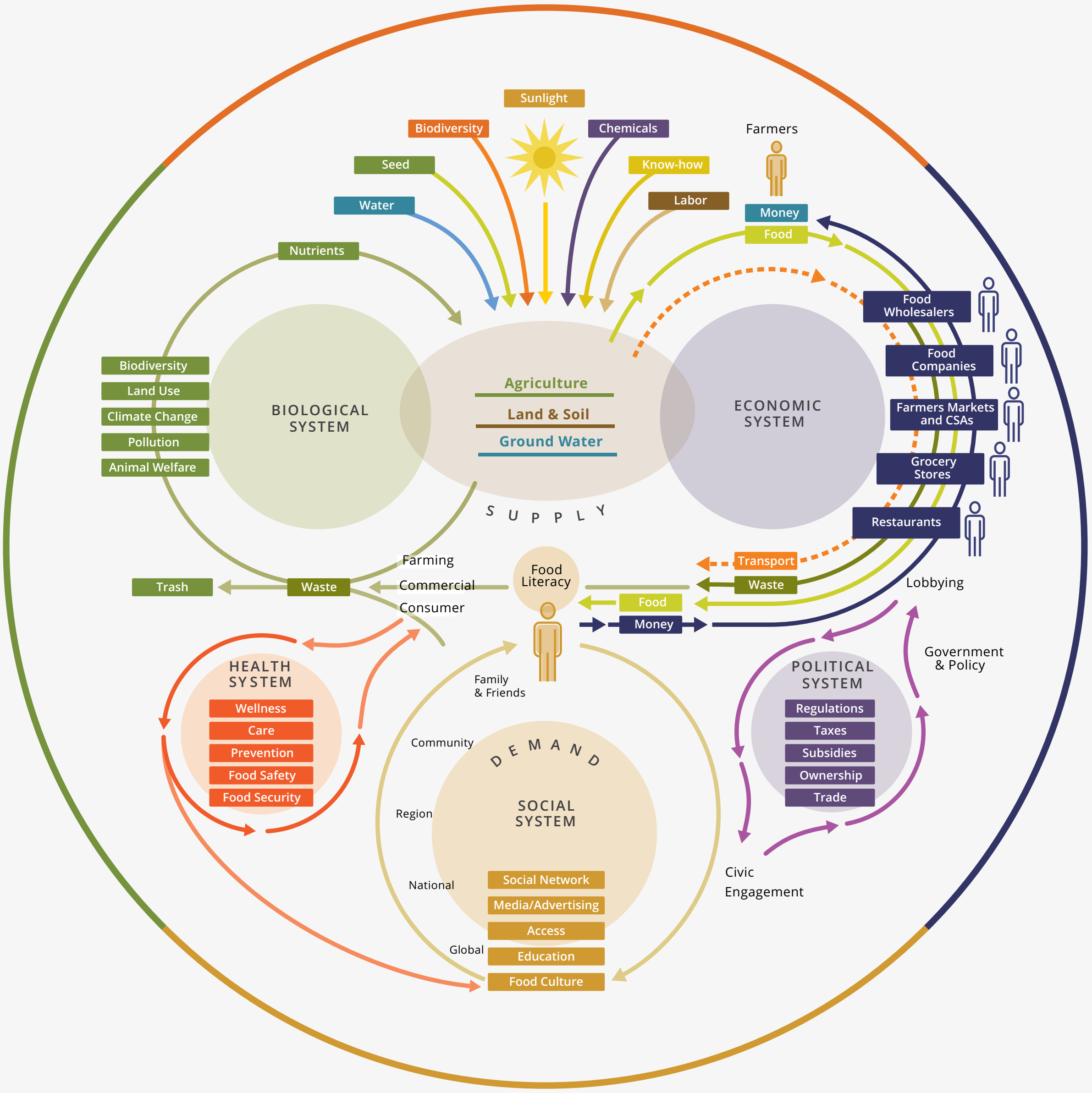
Box 2.8 Case study: Bayesian networks: a useful tool in applying systems thinking?

One of the key challenges in operationalising systems thinking is the integration of interdisciplinary knowledge to provide robust models for decision-making. McVittie *et al.* (2015) used Bayesian Networks (BN) to develop an ecological-economic model to assess the delivery of ecosystem services from riparian zone management on agricultural land. Also known as belief networks (or Bayes nets for short), BN belong to the family of probabilistic graphical models (GMs), which use graphical structures to represent knowledge about an uncertain domain (Ben-Gal 2007). For example, the interface between terrestrial and aquatic ecosystems contributes to the provision of important ecosystem benefits including clean water and reduced flood risk, and is heavily influenced by land use decisions and policy. A participatory workshop gathered scientific and policy stakeholders to explore the linkages across these ecosystems and their ecosystem services. This yielded extremely complex connections that would have presented a considerable modelling challenge. The use of a BN allowed the capture of elements of this complexity whilst focusing on the key interactions between underlying ecosystem processes and the delivery of ecosystem service benefits. An attractive feature of the BN approach is that it can combine quantitative and qualitative data to produce probabilistic outcomes that reflect the uncertainty of complex natural processes.

A second element in developing the BN model was the integration of values for the benefits of the water quality and flood risk services. These values can be monetary or non-monetary and as such can be derived using a variety of approaches (e.g. stated preference valuation, participatory workshops, multi-criteria analysis). The utility or value associated with different outcomes is in turn used to indicate the optimal management option.

Although the BN is a promising interdisciplinary and participatory decision support tool, there remains a need to understand the trade-off between realism, precision and the benefits of developing joint understanding of the decision context (McVittie *et al.* 2015). Important issues such as feedback loops and spatial and temporal factors are also not easily incorporated into BNs.

Figure 2.4 Food systems map that shows how multiple subsystems interact. (Source: the Nourish initiative)



Systems can be represented in multiple ways. **Figure 2.5**, for example, shows a holistic representation of food systems used by the Nourish initiative. They can also be described verbally, through mathematical equations, or by simulation approaches such as those commonly used in climate modelling and land use analysis (Malczewski 2004). These diverse approaches are used by systems scientists to simulate how systems function and, foremost, to improve our capacity to describe systems, and eventually predict system changes and outcomes caused by interventions.

Figure 2.5 shows material flows within the food system, but also flows of money and knowledge. Importantly, represented by the figures of humans, it shows how many dynamics are driven by individual and societal choices, rather than impersonal 'principles' or 'laws of nature.' Indeed, next to biological, economic and social systems, the political system is drawn separately to highlight its role in the food system. Understanding the food system by only accounting for the economic flows fails to account for other important driving factors.

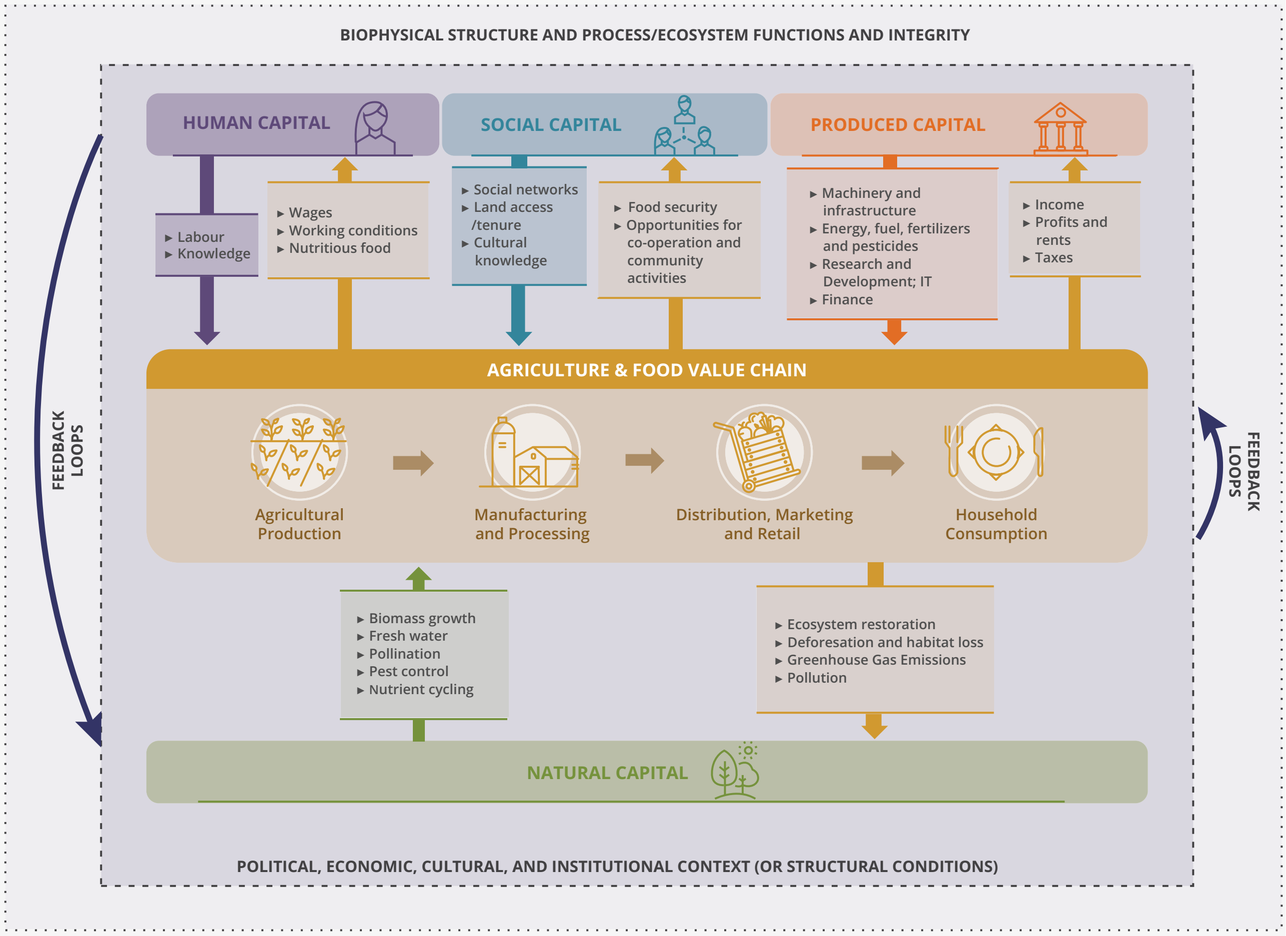
To highlight the fact that many different dimensions are involved in the eco-agri-food system and complex interconnections and feedback loops drive the relation between them, a slightly modified version of the "simplistic" system diagram of an archetypal eco-agri-food system is used in **Figure 2.6**. It illustrates the key components and linkages to be considered when assessing the eco-agri-food system, including the context in which the value chain is embedded, as well as some of the key system features discussed above. These include:

a) Value chain perspective and its macro contexts

The eco-agri-food system value chain encompasses all actors and activities involved in food production, processing, distribution, and consumption. Within the social and natural subsystems, the stages of an eco-agri-food value chain are tightly intertwined. Demand, production, and distribution of food all form closed loops that are simultaneously and heavily dependent on external influence as well as on internal dynamics. These are represented in **Figure 2.6** by the four stages of the value chain appearing horizontally in the middle of the figure. These stages are connected by two-way arrows showing (simplistically) examples of flows between capital stocks and the value chain in both directions.

Because value chains include activities from food production, postharvest through to consumers, they provide useful lenses for viewing the broader eco-agri-food system and identifying entry points for policies and interventions to improve system performance (Gelli *et al.* 2015). It is essential to understand the broader macro-level context, or enabling environment, within which the value chain operates, including policy and governance, political and economic context, culture, gender, equity, climate and environment (Hawkes *et al.* 2012). Biophysical structure and process both impact and are influenced by the eco-agri-food system; as are ecosystem functions and integrity. Whether these contexts are exogenous or endogenous to the system depends on the time horizon over which decisions are made.

Figure 2.5 Modified high-level 'systems' diagram of an archetypal eco-agri-food system (Source: adapted from authors of Chapter 1)



B) An inclusive conception of an economy's capital assets

Following the Inclusive Wealth Report (UNU-IHDP and UNEP 2014), the eco-agri-food system relies on the use of different types of capital, including: i) produced capital (roads, buildings, machines, and equipment), ii) human capital (skills, education, health), iii) social capital (or the "networks together with shared norms, values and understandings that facilitate cooperation within or among groups" (Healy and Côté 2001), and iv) natural capital (sub-soil resources, ecosystems, the atmosphere). Other durable assets, such as knowledge, institutions, culture, religion – more broadly considered as social capital - are considered enabling assets, assets that enable the production and allocation of the other three types mentioned before.

These types of capital are represented in **Figure 2.6** by the four outer boxes at the top and bottom of. From these boxes, arrows surround the value chain stages, representing the underpinning role of these capitals for the value chain. The eco-agri-food system not only depends on these capitals for various reasons along the value chain, but also, in turn, impacts these capitals, contributing to positive or negative change in quality, availability, and distribution across spatial and temporal scales.

C) Analysis of flows: impacts and dependencies on capitals

The flows of supply from each of the four types of capital (natural, social, human and produced) into the activities across the value chain are represented in **Figure 2.6** by vertical arrows 'inputting' toward each value chain stage. Examples of these inputs for the production stage include: i) inputs from natural capital such as energy, land fertility (e.g. nutrients and organic carbon), genetic diversity, water, and pollination services, ii) inputs from produced capital, such as machinery (e.g. tractors), agrochemicals and irrigation infrastructure, iii) inputs from human capital, such as labour, skills, and land management practices, and iv) inputs from social capital, such as knowledge and cultural practices. Among the examples provided above, some are unique inputs that contribute to a single stage of the value chain (e.g. nutrient cycling is used as inflow in the production stage), while others contribute to multiple stages across the value chain (e.g. fresh water is relevant to all stages of the value chain).

As a result of the activities developed in each stage of the value chain, outputs can have a positive or negative impact on society by affecting different types of capitals. These are represented in **Figure 2.6** by vertical arrows 'out-flowing' from the value chain towards the different capital types. Each stage of the value chain generates potential positive outputs, such as wages, food or carbon sequestration that lead to broader societal impacts, such as nutrition and food security (related to crop yield and income), social equity and human health (including nutrition and access to clean water). However, adverse or negative outputs can also arise, such as air and water pollution (e.g. from the use of chemical fertilizers and pesticides), and biodiversity loss (e.g. through habitat loss/fragmentation and agrochemical use); these negative outputs can also have health and social impacts.

D) System connections: feedback loops and cascading effects

A cascading effect can be noted between inputs and outputs, both within a single value chain stage and across the whole value chain. For instance, all stages require water, which is influenced by various uses (e.g. for irrigation and sanitation) and by the use of chemical inputs and waste (e.g. fertilizers and pesticides). If water is not properly managed, systemic consequences may emerge, where the consumption and contamination of water in one stage may affect all the others (processing and distribution and consumption), and also reach beyond the value chain to affect society.

Feedback loops should be highlighted across the value chain. Impacts on human health may raise awareness among the public about the impacts of unsustainable production, and thus lead to changes in consumer preferences, such as a shift to fair-trade or organic products. Subsequent changes in production practices and processing and distribution standards could improve the quality of food and reduce environmental impacts, resulting in mitigated or reduced health impacts.

A second feedback loop also emerges when considering the full value chain of the eco-agri-food system. The various stages of the value chain share inputs, which are affected by the outputs of all the stages of the eco-agri-food system. Tight interconnections pertain especially to the natural, human and social capital. In fact, with key natural resources being impacted at every stage of the value chain, and being used at each stage (e.g. water quantity and quality, air quality), the performance of the eco-agri-food system is influenced by every activity within its boundaries. Care must be taken when the various stages are dislocated in space, i.e. when natural resources are not shared across the value chain within the same landscape. This is not necessarily an advantage, nor a sign of resilience. Indeed, the lack of direct connections across the stages of the value chain may lead to an overexploitation of natural resources, because this unsustainable use could go unnoticed or unaccounted for a long period of time. It is essential to carefully define the system boundary, both spatially and temporally, to ensure the sustainability of the system.

E) Actors and their influence

There are many and varied actors influencing and being affected by the eco-agri-food system, which are described in more detail in Chapter 9. These include, among others, governments, NGOs, individuals (different than consumers already considered), financial institutions, other businesses and sectors, and research and academia, which in turn formulate, shape, or implement actions that influence and are affected by the system. These actors determine the performance of the different stages of the value chain, through regulations, financial requirements or engagement policies, campaigns, knowledge and innovations, etc.

2.3.3 An illustrative Causal Loop Diagram of a generic eco-agri-food system model

A causal loop diagram (CLD), i.e. a map of the system, is a way to represent and explore the interconnections between the key indicators in a sector or system. A CLD is thus an integrated map representing the dynamic interplay of different system dimensions and exploring the circular relations or feedbacks between the key elements—the main indicators—that constitute a given system (Probst and Bassi 2014).

CLDs make feedback loops visible, and thus the processes 'whereby an initial cause ripples through a chain of causation ultimately to re-affect itself' (Roberts *et al*. 1983, Probst and Bassi 2014). Two types of feedback loops exist, positive (or reinforcing) feedback loops that amplify change, and negative (or balancing) feedback loops that counter and reduce change. Regardless of the complexity of the system analysed and of the CLD created, only a handful of feedback loops may be responsible for most of a system's behaviour (Probst and Bassi 2014). Thus, if these dominating feedback loops can be identified, entry points for effective intervention, or policy levers, can also be detected.

The creation of a CLD has several purposes. First, it is a means to elicit and integrate a team's ideas, knowledge and opinions. Second, it requires the explicit discussion and defining of the components and boundaries of the analysis. Third, it allows all the stakeholders to achieve basic-to-advanced understanding of the analysed issue's systemic properties (Sterman 2000).

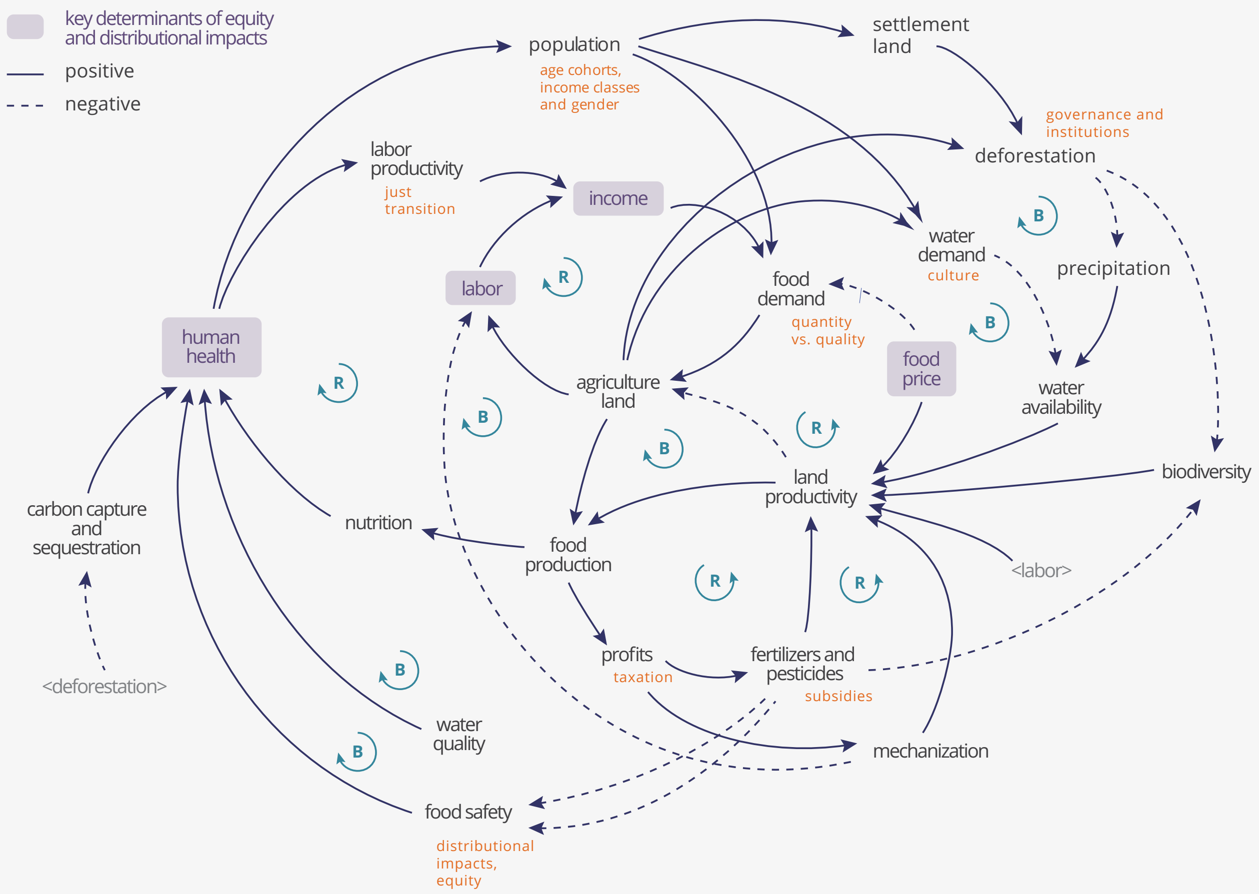
Shared understanding is crucial for solving problems that influence several sectors or areas of influence. When the process of creating a CLD involves broad stakeholder participation, all parties involved need a shared understanding of the factors that generate the problem and those that could lead to a solution. As such, the solution should not be imposed on the system, but should emerge from it. In this context, the role of feedbacks is crucial. It is often the very system we have created that generates the problem, due to external interference or to a faulty design, which shows its limitations as the system grows in size and complexity. In other words, the causes of a problem are often found within the feedback structures of the system.

Figure 2.7 represents a stylized CLD to illustrate some generic relations and system dynamics of the eco-agri-food system. This CLD highlights selected feedback loops that are generally thought to be responsible for the trends observed in the last decades. This CLD does not attempt to comprehensively capture all elements and relationships. It is presented for illustrative purposes to highlight the emphasis on indicators, their interconnections, and the feedback loops that these interconnections form. For instance, we capture the impact of deforestation on water (as an ecosystem service that supports agriculture) as an example of ecosystem service change that resulted from land use choices, but other important elements such as the effects on specific species (currently lumped under biodiversity) are not included here.

Specifically, one of the key drivers of the eco-agri-food system is food demand, which is primarily driven by population and income and also by different industries that convert agricultural production to products beyond food, such as biofuels, additives, livestock feed etc. An increase in demand for these items can lead to the expansion of agriculture land, growth in employment and income, and hence more food demand. This circular relationship represents a positive, or reinforcing (R1) feedback loop, which leads to growth. Further, an expansion of agricultural land would lead to higher food production (all else equal), which would have two main effects. The first one (a) would increase access to food and nutrition, having a positive impact on human health and population (R2) and on labour productivity and income (R3). Two more reinforcing loops are therefore identified, leading to more food demand and land conversion. The second effect (b) emerges over time, with the accumulation of profits and with the improvement of knowledge and technology. This generally leads to an increase in mechanization and the use of fertilizers and pesticides, leading to higher land productivity. This in turn has three main effects, it increases production in terms of higher yield per hectare (R4 and R5); it lowers food prices, which increases food demand (R6); and reduces the amount of land required (B1), all else equal.

At this stage, the eco-agri-food system in **Figure 2.7** is dominated by reinforcing loops, and shows a trend of growth over time. The increase of population and thus demand, leads to the expansion of agricultural land, improved employment and income, as well as increased nutrition, potentially leading to increased population. When this growth is coupled with an increase in land productivity and a reduction in food prices, we generally expect growing demand, production and profits.

Figure 2.6 Illustrative Causal Loop Diagram of a generic eco-agri-food system (Source: authors)



On the other hand, several balancing loops, which constrain growth, also emerge. First, with the adoption of mechanization, labour intensity declines. This leads to higher production and profits for producers, but lowers the potential growth of employment and income (B2), possibly leading to growing inequality. Further, the use of fertilizers and pesticides has negative impacts on water quality (B3) and food safety (B4), two factors that negatively affect human health, and hence labour productivity and population. Finally, the expansion of agricultural land, and the growth of population (and hence the expansion of settlement land) might take place at the expense of forest or vegetation cover. The loss of biodiversity, carbon storage and sequestration with increased carbon emissions can further negatively impact human health (B5), the hydrological cycle, and possibly the productivity of agricultural land (e.g. due to sedimentation, runoff of fertile topsoil or erosion) (B6).

As a result, the growth observed historically (and determined by reinforcing loops) is the cause for the emerging challenges (represented by balancing loops) being faced by the eco-agri-food system: increased reliance on fertilizers and pesticides, more frequent water shortages, an increasing trend of deforestation and growing health impacts (primarily related to the quality of food and nutrition). A silo approach considering individual actors and relying solely on economic indicators would not make visible the emergence of these side effects.

2.4 CONCLUSION

The fact that components or subsystems of the eco-agri-food system are interconnected and interdependent is undisputed. This chapter builds on that observation to make the case for systems thinking as a guide for the conceptualization and analysis of the eco-agri-food system, on which the subsequent chapters of this report offer a concrete attempt to advance.

The many dimensions of the eco-agri-food system create complex analytical and policy challenges. A first step toward a necessary paradigm shift is a re-assessment of how we conceptualise and interpret the problems of the global food sector and how we choose methods to analyse them. To conceptualise what constitutes a sensible operating space for the eco-agri-food system, we draw on the concept of "safe and just operating spaces for humanity" (Rockström *et al.* 2009a; 2009b; Raworth 2012; 2017), emphasizing that we must respect the planetary boundary (e.g., biophysical constraints) while simultaneously addressing social and development objectives (such as health, gender equality, social equality, and jobs). A sustainable eco-agri-food system can only be achieved if the social and environmental dimensions are also taken seriously, in addition to the economic dimension. Silo approaches are limiting our ability to achieve a comprehensive understanding of the interconnected nature of the many challenges we face, and that we need a holistic framework allowing the integration of well-understood individual pieces into a new, complete picture. Indeed, synergies and coherence can be gained when evidence is generated and used based on concepts and methods aligned with systems thinking.

The shortcomings of current approaches also include the limited availability of data and methods for the analysis of the eco-agri-food system as a complex system. In this chapter we use several examples to explain the limitations of currently applied conceptualizations and analytical tools. We call for expanding the analytical boundary and adopting analytical tools guided by an integrated approach based on systems thinking.

This chapter offers a conceptual representation for the eco-agri-food system, presenting a general overview of the key components and linkages that need to be examined in order to understand the dynamics of the system, as well as the contexts within which the eco-agri-food system value chain is embedded. A stylized Causal Loop Diagram is presented to illustrate some generic relations and system dynamics of the eco-agri-food system. The key elements, dynamics, and relationships will be fleshed out in Chapters 3, 4 and 5. The TEEBAgriFood Evaluation Framework presented in Chapter 6 advances on such analysis by attempting to examine all potential impacts and consequences of the respective subsystems.

"Transformability," defined as "the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable," is about shifting development into new pathways and even creating novel ones (Folke 2006, Folke *et al.* 2010, Walker *et al.* 2004). Implementing the TEEBAgriFood Evaluation Framework for the eco-agri-food system puts us in a much better position in the transformative process to understand the full set of impacts of externalities, costs and benefits, particularly on the public goods affected, and thereby identifies what changes would be required for a more balanced and equitable development approach. Further, empowered by systems thinking, the TEEBAgriFood Framework's contribution goes beyond technical analysis by contributing to actively enlisting support for systemic transformations across the stakeholder continuum (see Chapter 9). Systems thinking adopted for the eco-agri-food system can aid forming a common ground for cultural changes through promoting more integrated approaches.

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CHAPTER 3

ECO-AGRI-FOOD SYSTEMS: TODAY'S REALITIES AND TOMORROW'S CHALLENGES

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SUMMARY

Chapter 3 provides an overview of the diversity of agriculture and food systems, each with different contributions to global food security, impacts on the natural resource base and ways of working through food system supply chains. We describe "eco-agri-food systems" and further identify their many manifestations through a review of typologies. We identify challenges ahead with existing systems due to prevailing economic and political pressures resulting in patterns of invisible flows and impacts across global food systems. We describe pathways to ensure sustainability by securing the benefits from working with, rather than against, natural systems and ecosystem processes and the challenges for farmers, communities and societies to reorient food value chains and build resilience in eco-agri-food systems.

CONTENTS

FIGURES, TABLES AND BOXES

CHAPTER 3

3.0 KEY MESSAGES

- This chapter provides an overview of the complexities, roles and functions of eco-agri-food systems. The diversity of global agriculture and food production systems is profiled; the challenges ahead for the world's agriculture and food systems are presented; and pathways to sustainability for agriculture and food systems, building on ecosystem services and biodiversity, are explored.
- Globally, there many diverse types of agriculture and food systems, each with different contributions to global food security, impacts on natural resources and varying ways of working through food system supply chains. Using a typology recently adopted by international initiatives, the world's food systems can be characterized as traditional, mixed and modern. Each of these systems can strengthen their linkages to natural capital and ecosystem service provisioning.
- The contribution of small and medium sized farms of traditional and mixed systems – providing food to an estimated two thirds of the world's population in highly diverse landscapes – is highlighted, reinforcing the contribution of ecosystem services and biodiversity in food and agriculture.
- Prevailing economic logic reinforces forms of food production that fail to account for the contributions of nature, while negatively impacting both the environment and human welfare. This situation has created externalities such as wide¬spread degradation of land, water and ecosystems; high greenhouse gas emissions; biodiversity losses; chronic over- and undernutrition and diet-related diseases; and livelihood stresses for farmers around the world. The nature of international trade resulting from such forces and pressures has many ramifications for equity and sustainability.
- An emerging feature of global food systems is the existence of multiple, insidious forms of visible and invisible flows of natural resources. Socio-economic crises and the often-unpredictable impacts of climate change present additional and compounding challenges for farmers and local communities.
- Pathways to sustainability, going forward, must recognize and strengthen those forms of agricultural production that explicitly enhance biodiversity and ecosystem services and build the natural capital that underpins food systems, creating regenerative forms of agriculture and food systems that generate positive externalities.
- Pathways to sustainable food systems must look at the dependencies and interactions within the entire food chain and at multiple scales, from farm to landscape to city to regional food systems.

CHAPTER 3

ECO-AGRI-FOOD SYSTEMS: TODAY'S REALITIES AND TOMORROW'S CHALLENGES

3.1 INTRODUCTION TO AN 'ECO-AGRI-FOOD' SYSTEM APPROACH

Food—the ultimate source of energy and nutrients—is the central reason for agricultural production around the world (TEEB 2015) and sustains human life (Vivero-Pol 2017). The increasing complexity of the global food system and its intricate linkages with other systems related to energy, health, soils, water, human knowledge, ecosystems, etc. are changing how food systems function. To grasp this complexity and deepen the understanding of the role and function of food systems, TEEB for Agriculture & Food (TEEBAgriFood) is presenting a broadly encompassing perspective that goes beyond the production, processing, transport and consumption of food. As defined by TEEB, an 'eco-agri-food' system refers to the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.

This chapter explores the underpinnings of the 'eco-agri-food system', first by reviewing the predominant trends and patterns in the ways that agriculture and food goods are being produced globally. As human populations have grown over time, agriculture and food production systems have experienced dramatic changes, increasing the levels of production well beyond what could have been imagined a hundred years ago. Yet as these systems have become increasingly productive and global in nature, significant challenges are impacting upon them. Global issues related to food security and sovereignty, nutrition and health, climate change, migration and economic crises show that current food systems are not functioning adequately and are in dire need of reconfiguration. Since the 1950s, with the growing demand for agricultural produce, many farmers began using non-renewable energy-based chemical fertilizers and agricultural processes became specialized and more monocultural. Ways of processing and distributing food have emphasized low cost and high productivity while often devaluing the freshness or wholesomeness of food. We must be reminded that agriculture and food production are fundamentally biological processes, reliant on biodiversity and ecosystem functions and processes. Agriculture imposes a heavy toll on the environment when it tries to escape its essential biological limits, yet at the same time these ecological functions are key to the sustainability and regenerative potential of farming and food systems. Many multinational, national and local organizations and initiatives are attempting to change the existing pattern so that proper balance with environment is created and any conflict (economic, political, social) is minimized. TEEB is one of these efforts, in particular seeking to develop the tools to value ecological functions that contribute to our food system, and the negative and positive externalities that emanate from managing theses agricultural and food systems. TEEBAgriFood aims to offer an integrated and holistic perspective that brings such issues into focus.

In this chapter, we unpack the eco-agri-food system, and identify its many manifestations through a review of typologies (Section 3.2). We then identify the challenges ahead (Section 3.3) and finish with a section (Section 3.4) describing pathways to improve the status of agricultural and food systems by securing the benefits derived from working with, rather than against, natural systems and ecosystem processes.

3.2 TYPOLOGIES OF ECO-AGRI-FOOD SYSTEMS

3.2.1 Definition of eco-agri-food systems

In Chapter 1, the eco-agri-food system was introduced. In Chapter 2, generic features of eco-agri-food systems were described, and the importance of understanding multiple interactions and dynamics through systems thinking was highlighted. In this chapter, we aim to unpack those generic features, and characterise the diversity and salient aspects of the main food systems found around the globe that are of relevance to a TEEBAgriFood analysis.

3.2.2 Characterizing the diversity of eco-agri-food systems

At a broad spatial scale, one may define an agricultural system as the land area in a region, district, or landscape that produces a particular commodity or various crops (Jones et al. 2016). TEEB (2015) defines 'agricultural system' as an assemblage of components which are united by some form of interaction and interdependence and which operate within a prescribed boundary to achieve a specified agricultural objective on behalf of the beneficiaries of the system". For our purposes, we are focusing on agricultural systems with respect to the integration of their different components such as natural resources, energy, labour, marketing, finances, genetic stock, nutrition, equipment, and hazards—thus the broader food system. This has been defined as the interdependent sets of enterprises, institutions, activities and relationships that collectively develop and deliver material inputs to the farming sector, produce primary commodities, and subsequently handle, process, transport, market and distribute food and other agro-based products to consumers (UNEP 2016). It thus includes production, harvesting, storage, processing, packaging, marketing, trade, transport, demand, preparation, consumption and food disposal. It thus includes production, harvesting, storage, processing, packaging, marketing, trade, transport, demand, preparation, consumption and food disposal. As a system, it extends to inputs needed and outputs generated at each step as well as governance, research, education and varied (e.g. financial) services around food provisioning.

Food (value) chains are one of the core elements of a food system that feed a population. Clearly, value chains are created around economic value and respond to supply and demand. However, they can also impact and be impacted by issues related to the environment, nutrition, equity, quality, cultural acceptability of food. Food systems also include political, economic, socio-cultural and environmental drivers and outcomes that affect actors and stakeholders. Thus, the definition of food systems should include activities (from production to consumption), outcomes of the activities (food security, ecosystem services, biodiversity, social welfare), and interactions between and within biogeophysical and human environments (Ericksen 2008). The interactions among these components may become more important than how each component functions independently.

Diversity in agriculture is the result of the co-evolution, in time and space, of human societies and ecosystems, through the practice of farming, unfolding in different patterns of resource use and development trajectories (Ploeg and Ventura 2014). The heterogeneity of farming systems reflects the diversity of social, economic and ecological responses to changing adaptive conditions in different settings (Ploeg 2010).

Certainly, there are unlimited permutations of the components of eco-agri-food systems, and a great number of ways of characterizing these. Often contrasting systems are described as dichotomous entities, from traditional peasant systems to "modern" food systems, or as those characteristic of developed versus developing countries. From the TEEBAgriFood perspective, there are many different types of agriculture and food systems, each with different contributions to global food security and different impacts on the natural resource base. If we are to better understand the possible pathways towards sustainable food systems and to encourage intervention from different stakeholders around the world, we need a workable way of characterizing this diversity.

Within a TEEBAgriFood perspective, we suggest it is most productive to adopt current typologies as developed by ongoing international processes, and to take these as a starting point to further describe the pathways that diverse systems may take to recognize externalities and reorient toward more sustainable solutions. A useful typology is that developed by the International Resource Panel of the United Nations Environment (UNEP 2016) and the related High-Level Panel of Experts on Food Security and Nutrition's report on Nutrition and Food Systems (HLPE 2017).

The International Resources Panel recognizes the diversity of food systems across the world, and their multifarious interactions: nonetheless, distinguishing between traditional food systems, mixed food systems, and modern food systems can be helpful. Salient characteristics of these, relevant for the TEEBAgriFood Evaluation Framework, are described below (UNEP 2016; HLPE 2017).

Before presenting the aligned typologies of the HLPE and UNEP, we should note that the Global Nutrition Report (IFPRI 2015) has developed a food system classification on a country level that considers differences between industrial, mixed, transitioning, emerging and rural food systems; this typology maps to the three classifications mentioned above (and by the International Resource Panel and the HLPE Report), but with a finer level of distinction and disaggregation to national levels.

The three classifications – traditional food systems, modern food systems, and mixed food systems - are described in detail in Table 3.1 and the sections below (while noting that these are not distinct categories, but rather a way of classifying a complex continuum):

Traditional food systems: These may also be considered low-external input-intensive food systems, which primarily make use of naturally generated inputs, human knowledge and skills, and production practices that have been maintained by communities over generations. Yields and productivity tend to be low in comparison to high-input systems, although societies within traditional food systems generally value benefits well beyond production and income. Under often challenging biophysical conditions, traditional food systems have often developed ways of sustaining agricultural production in places where modern, mechanized agriculture would not succeed. Agricultural products are either self-produced or sold in local markets and are largely unprocessed, or are processed by the local consumers. Production, trade and processing takes place in small-scale operational units. Linkages with larger commercial operations are scarce. Consumption patterns correspond to seasonal harvests, and are usually dominated by plant-based products, (although a considerable component of traditional communities such as pastoralists, fisherfolk, and forest dwellers may specialize in livestock, fish or wild meat and honey, respectively). Access to perishable foods such as certain fruits and vegetables and animal source foods depends on proximity to the source; thus, local markets are highly important for food security and nutrition. As food security primarily depends upon local sources, pressures on these sources such as extreme weather events or population changes demand new, usually local responses.

Examples of traditional food systems include Andean agricultural systems where farming communities cultivate more than 1,000 native varieties of potatoes adapted to different environments ascending the Andes under terrace management. The Ifugao rice terraces in the Philippines have retained their viability and efficacy over 2000 years in a system intimately intertwined with that of the local communities' culture and beliefs, religious rituals and traditional environmental management and agricultural practices (Koohafkan and Altieri 2011).

Traditional food systems often include an important livestock component, such as pastoralism. The Maasai in Kenya and Tanzania, for example, practice a pastoral system, in its essential elements, that is over 1000 years old. To this day, it strikes a social and environmental balance in a fragile environment, sustaining livestock production and conserving critical habitat for wildlife (Koohafkan and Altieri 2011). In Europe, the transhumant pastoralists in Eastern Spain, or the Sami people in the artic are among hundreds of good examples of communities employing traditional food systems.

Small-scale fisheries are another important production system for subsistence or local markets, often using traditional fishing techniques and small boats. Collectively, small-scale fisheries catch a large proportion of all fish caught for human consumption, and employ 90% of the labour involved in capture fisheries (FAO 2o16b).

Traditional systems tend to have low use of external inputs and focus on stability rather than increase in production. Communities practicing traditional systems sustain themselves by engaging in cultural activities that, tied to the traditions of certain communities and inherited forms of production, replicate and improve their own production and consumption systems, incorporating cultural and religious elements, as well as social practices, for the management of resources.

Modern food systems: These are systems that are generally characterized as high external-input, high productivity systems, with a strong dependence on purchased or external inputs such as modern crop seeds, fertilizers, pesticides and fuel-based mechanical inputs. There is a strong economic incentive to avoid risks of crop loss by over-applying both pest control and fertilizers, resulting in on-site pollution, run-off and contamination of adjacent land and water. The impacts of intensive agricultural systems on soil health, freshwater quantity and quality, greenhouse gas emissions, and the capacity to conserve biodiversity and generate ecosystem services may be strongly negative (Pingali 2012; Godfray et al. 2010).

While farming systems may be considered "modern", farmers around the world are generally operating at small margins, sometimes compensated by government subsidies. Capacities to invest in more regenerative practices are thus limited. Crops and livestock rearing systems, often closely connected in traditional systems, are generally separated in modern food systems. The processing, distribution and retail sides of the food chain in modern food systems are usually specialized and elaborate, and provide substantial employment and value addition, but are also greenhouse gas-intensive. The modern food system is characterized by specialized input producers and agricultural companies, operating at large and often transnational scale. The production focus now includes not only food for direct human consumption, but also biofuels and animal feed. The processing and retail segments of modern food systems have a major influence on both production systems and consumer behaviour. Consumers in modern food systems have the choice to purchase food from sources all over the world, much of it in a processed form. However, "food deserts1" and "food swamps2" may be common in low-

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1 Described as geographic areas where residents' access to food is restricted or non-existent due to the absence or low density of "food entry points" within a practical travelling distance (HLPE 2017)

2 Described as geographic areas where there is an overabundance of "unhealthy" foods but little access to "healthy" foods. (HLPE 2017)

income areas, creating areas of food insecurity within modern food systems. Consumption of meat, trans fats and sugary foods is much higher in modern systems than in other food systems. The cost of staples, such as rice and wheat flour, is lower than animal-sourced foods and perishable fruits and vegetables. Consumers have access to fairly complete information on food labels, and dietary guidance is widely disseminated, though not necessarily widely used. Modern food systems are associated with comparatively lower levels of undernutrition (although concentrated areas do occur), but higher levels of overweight and obesity (Ng et al. 2014).

More recent trends in modern food systems include greater reliance on modern biotechnology such as genetic modification, molecular markers, hydroponics and precision-farming tools (e.g., GPS, GIS, satellite images, automatic mapping) and procedures that increase the application efficiency of inputs (Pingali 2012). For example, in places with land or weather constraints, experimentation with hydroponics is underway. In Japan, rice is harvested in underground vaults without the use of soil. Israel also, where the management of water is a key point, is experimenting with these new tools and innovations. In USA, hydroponics farming revenues reached $821 million nationwide in 2016, growing at a rate of four to five per cent since 2011, with 2,347 hydroponic farms (Ali 2017).

A parallel trend within modern food systems is a return to more organic, local/small-scale and diversified practices, from production to retail sales. Major aspects of this trend can be captured under the umbrella of agroecology, in its different aspects as a science, a practice and a movement (Wezel et al. 2009). As a science, agroecology reorients agronomic science to build on the ecological foundations of farming and agriculture, combining different elements of nature and its services to maximize synergies between them. As a practice, agroecology is not prescriptive; it is based on applying a set of principles (for example, "enhance recycling of biomass, optimizing nutrient availability and balancing nutrient flow") to local contexts (TWN-SOCLA 2015). As a social movement, the focus of agroecology has moved from the field and farm scale to the entire food system, emphasizing the importance of building food networks that link all parts of the food system, and advocating for social equity and food system transformation (Gliessman 2015). The farming traditions that reflect the application of agroecological principles in one form or another include: 'permaculture' associated with the ecologist Bill Mollison, 'biodynamic farming' following the principles of the anthroposophist Rudolf Steiner, the 'one-straw revolution' founded by the Japanese farmer Masanobu Fukuoka, the 'Biointensive' farming system popularized in the U.S. by John Jevons, the 'No Tillage' movement in Brazil led by Ana Primavesi, 'Agroecology' as described by Miguel Altieri and Stephen Gliessman in the U.S., Latin America, Africa and Asia, and the wide range of farming systems that in one way or another subscribe to the formal definition of 'organic farming' institutionalized by the International Federation of Organic Agriculture Movements (IFOAM). These food systems are often meant for international markets, but also used for home consumption, solidarity markets and other approaches to land and food sovereignty such as promoted by La Via Campesina, the international movement of Agrarian Federations for Farmers in the world.

Mixed food systems: While most 'modern' food systems may be found in Europe, the U.S. and other industrialized countries, and 'traditional' food systems are far more common in less industrialized regions, a vast range of intermediate, or 'mixed', food systems exist throughout the globe, supplying food to an estimated four million people. Particularly in Latin America, Asia, Eastern Europe and in some African countries, small and medium-sized farms provide the majority of food to local and national populations. In mixed systems, farmers integrate or incorporate some elements of different technological packages; for example, they may use pesticides and fertilizers, but plant farmer-saved, traditional varieties. Food producers rely on both formal and informal markets to sell produce. The food systems, however, are not uniformly small scale; the processing and retail segments of the system are often quite commercialized and in the process of becoming linked into regional and global value chains. Consumers may purchase most of their food in local or street markets, but other supermarkets and processed food purveyors are growing as market presences. Processed and packaged foods are more accessible than under traditional food systems, while nutrient-rich foods, such as fruits, vegetables and nuts, are more expensive. A further notable change is that food advertising is pervasive, and while food labelling may appear on packaged foods, most consumers are not well informed on dietary guidelines and use of labelling to balance diets. Malnutrition, both in terms of undernutrition and overweight/obesity, occurs in intermediate or mixed food systems, with many challenges remaining on how to address these both in policy and programmes.

Current trends in intermediate (mixed) food systems include the growing importance of urban agriculture, in developed and developing countries alike. For example, urban horticulture in the Congo reaps $ 400 million for small growers, giving incomes, and labour and food security (FAO 2011b).

Table 3.1 Details of the key features of these food systems typologies, which serve to distinguish key elements across a complex continuum from traditional to modern. (Source: adapted from Ericksen (2008), UNEP (2016) and HLPE (2017), except where otherwise noted)

Food system feature	“Traditional’ food systems	Intermediate/mixed food systems	“Modern’ food systems*	Source
Estimated number of people in system	~1 billion	~4 billion	~2 billion	Ericksen (2008), UNEP (2016)
Principal employment in food sector	In food production	In food production	In food processing, packaging and retail	Ericksen (2008), UNEP (2016)
Supply chain coordination system	Ad-hoc, spot exchange	Mainly ad-hoc, spot exchange	Contracts, standards, vertical integration	Ericksen (2008), UNEP (2016)
Food production system	Diverse, mixed production system (crops and animal production) by smallholders; local and seasonal production with varied productivity and diverse benefits; low input farming systems. Food systems are the main source of energy.	Combination of diverse, mixed production system and specialised operations with a certain degree of inputs, including fossil fuels, by both local smallholder farmers and larger farms often further away. Less dependence on seasonal foods.	Few crops dominate (i.e. largely monoculture); specialisation and high productivity; high external inputs, including fossil fuels. Food production consumes more energy than it delivers. Overall, the system produces a wide array of foods that are available globally.	Adapted from Ericksen (2008), UNEP (2016)
Typical farm	Family-based, small to moderate	Combination of smallholder farms and larger farms / fishery operations	Industrial, larger than in a traditional setting	Ericksen (2008), UNEP (2016)
Storage and distribution	Lack of adequate roads makes transporting food difficult and slow, leading to food waste. Poor storage facilities and lack of cold storage makes storing food, especially perishables, difficult	Improvements in infrastructure with better roads, storage facilities and access to cold storage; however not equally accessible, especially for the rural poor	Modern roads, storage facilities and cold storage facilitate food transport over long distances, and to store food safely for long periods of time	HLPE (2017)
Supply chain coordination system	Ad-hoc, spot exchange	Mainly ad-hoc, spot exchange	Contracts, standards, vertical integration	Ericksen (2008), UNEP (2016)

Typical food consumed:	Basic locally-produced staples	Combination of basic products and processed food	Larger share of processed food with a brand name, more animal products	Ericksen (2008), UNEP (2016)
Processing and packaging	Basic processing is available such as drying fruit, milling grains or processing dairy products. Little or limited packaging occurs	Highly processed packaged foods emerge and are more accessible.	Many processed packaged foods are easily available, often cheap and convenient to eat, but sometimes unhealthy	HLPE (2017)
Foods bought from (Retails and Markets):	Small, local shop or market	Small, local shop or market, share of supermarkets small but rapidly growing	Predominantly large supermarket chain, food service and catering (out of home)	Modified from HLPE (2017)
Nutritional concern	Undernutrition, and micronutrient deficiencies	Both undernutrition and diet-related diseases	Diet-related diseases	Ericksen (2008), UNEP (2016)
Economic access (affordability)	Food is a large portion of the household budget. Staples tend to be significantly less expensive relative to perishables (animal source food, fruits and vegetables)	Food places moderate demands on household budgets. Staples are inexpensive, whereas perishable foods are expensive. Many highly processed and convenience foods are inexpensive	Food demands less of the household budget. The price of staples is lower relative to perishables, but the difference is less stark than in the other food systems.	HLPE (2017a)
Main source of national food shocks	Production shocks	International price and trade problems	International price and trade problems	Ericksen (2008), UNEP (2016)
Main source of household food shocks	Production shocks; may be more resilient than capital-intensive systems (see Altieri 2002)	International shocks leading to food poverty	International shocks leading to food poverty	Ericksen (2008), UNEP (2016), Altieri 2002
Major environmental concerns	Soil degradation, land clearing, water shortage	Combination of concerns in traditional and modern systems	Emissions of nutrients and pesticides, water demand, greenhouse gas emissions, and others due to fossil fuel use	Ericksen (2008), UNEP (2016)
Influential scale	Local to national	Local to global	National to global	Ericksen (2008), UNEP (2016)

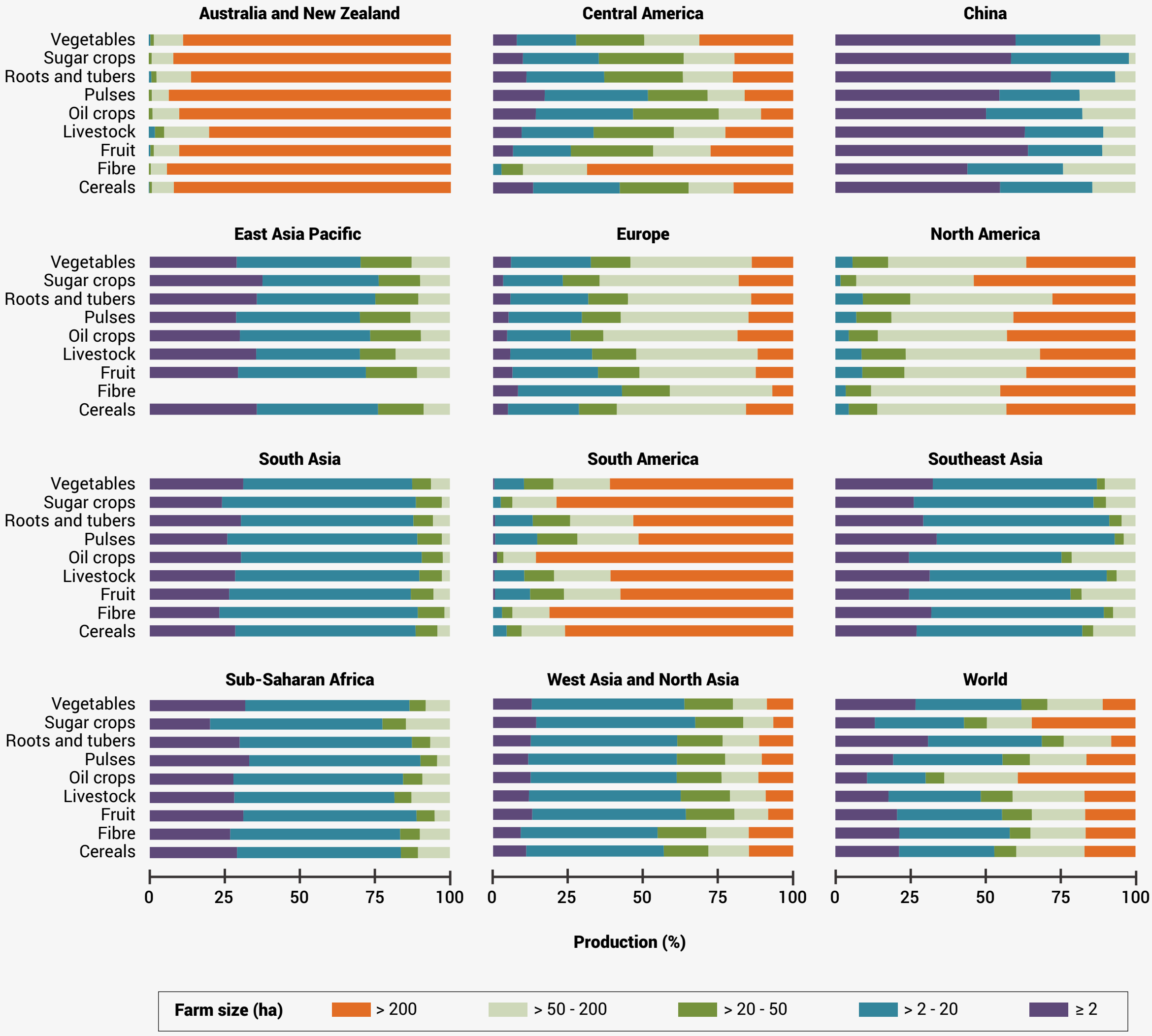
*It should be noted that the parallel trends within modern food systems as noted above - fostering agroecological, small scale and diversified systems - do not correspond to the features presented here.

3.2.3 Differential contribution of diversefood systems to global food and nutrient production

A basic typology of food systems (traditional, intermediate/mixed and modern) permits a more focused consideration of how different food systems contribute to global food and nutrient production. A key point from a recent paper by Herrero et al. (2017) is that understanding the differential contributions of diverse food systems is essential. Within this paper, the authors provide a breakdown not just of global agricultural production but also of nutrient production, by farm size. While there are no clear cut-offs in farm size between different food systems, small to medium sized farms tend to be found in traditional and mixed food systems, while larger industrial farms are part of modern food systems.

The Herrero et al. (2017) report finds that globally, small and medium farms (≤50 ha) produce 51–77 per cent of nearly all commodities and nutrients examined here, with key regional differences. As can be seen in Figure 3.1, small farms (≤20 ha) produce more than 75 per cent of most food commodities in the populous regions of Sub-Saharan Africa, Southeast Asia, South Asia, and China. Very small farms (≤2 ha) are important and have local significance in Sub-Saharan Africa, Southeast Asia, and South Asia, where they contribute to about 30 per cent of most food commodities. In Europe, West Asia and North Africa, and Central America, medium-size farms (20–50 ha) also contribute substantially to the production of most food commodities. Large farms (>50 ha) dominate production in North America, South America, and Australia and New Zealand. In these regions, large farms contribute between 75 per cent and 100 per cent of all cereal, livestock, and fruit production. This pattern is similar for other commodity groups.

Figure 3.1 Production of key food groups by farm size (Source: adapted from Herrero *et al.* 2017)



The Herrero et al. (2017) study also looked at how the diversity of food production changes with the diversity of agricultural landscapes and production systems. They documented that the majority of vegetables (81 per cent), roots and tubers (72 per cent), pulses (67 per cent), fruits (66 per cent), fish and livestock products (60 per cent), and cereals (56 per cent) are produced in diverse landscapes (taken as the number of different products grown within a geographic area). Similarly, the majority of global micronutrients (53–81 per cent) and protein (57 per cent) are also produced in more diverse agricultural landscapes. By contrast, the majority of sugar (73 per cent) and oil crops (57 per cent) are produced in less diverse ones (H≤1·5), which also accounts for the majority of global calorie production (56 per cent). The diversity of agricultural and nutrient production diminished as farm size increase, but regardless of farm size, it is shown that areas of the world with higher agricultural diversity produce more nutrients (ibid.).

Thus, it is evident that both small and large farms are important contributors to food and nutrition security, but very small, small and medium sized farms (found mostly in traditional and mixed food systems) produce more food and nutrients in the most populous regions of the world than large farms in modern food systems. Maintaining diverse agricultural landscapes, globally, is linked to producing diverse nutrients in viable, sustainable landscapes.

3.2.4 Inland fisheries and livestock production

Woven into the three typologies presented above are different ways of incorporating and managing the important components of inland fisheries and livestock production. The Herrero et al. (2017) study discussed above included seven livestock and 14 aquaculture and fish products; nonetheless, as these are often quite distinctive production systems, and a further profile of their production patterns is provided here.

Production in **Inland fisheries**: The world's apparent fish consumption is projected to increase by 31 million tons in the next decade to reach 178 million tons by 2025. The driving force behind this increase is rising incomes and urbanization, interlinked with the expansion of fish production and improved distribution channels. Per capita fish consumption is expected to increase in all continents, with Asia, Oceania and Latin America and the Caribbean showing the fastest growth. In particular, major increases are projected in Brazil, Peru, Chile, China and Mexico. Consumption of fish will remain static or decrease in a few countries, including Japan, the Russian Federation, Argentina and Canada (FAO 2016b). While much of this production comes from wild ocean fisheries, in the last two decades, a dramatic growth in aquaculture production has boosted the average consumption of fish and fishery products at the global level. The shift towards relatively greater consumption of farmed species compared with wild fish reached a milestone in 2014, when the farmed sector's contribution to the supply of fish for human consumption surpassed that of wild-caught fish for the first time (HLPE 2014).

Although annual per capita consumption of fish has grown steadily in developing regions (from 5.2 kg in 1961 to 18.8 kg in 2013) and in low-income food-deficit countries (LIFDCs) (from 3.5 to 7.6 kg), it is still considerably lower than that in more developed regions, even though the gap is narrowing. In 2013, the per capita fish consumption in industrialized countries was 26.8 kg. In 2013, fish accounted for about 17 per cent of the global populations' intake of animal protein and 6.7 per cent of all protein consumed. Moreover, fish provided more than 3.1 billion people with almost 20 per cent of their average per capita intake of animal protein.

As noted above, capture fisheries, which includes the artisanal fisheries characteristic of traditional and mixed farming systems, contribute about 50 per cent of fish production globally, with aquaculture—as part of modern farming systems contributing the remaining half. Growth in aquacultural production, however, is increasing rapidly, while yields from capture fisheries have largely plateaued.

Inland fisheries can be separated into two categories—**capture fisheries and aquaculture systems.** Inland capture fisheries are characteristic of the artisanal nature of fisheries in traditional food systems, while aquaculture, with a growing sophistication of technology, is considered within modern food systems. As illustrated by **Figure 3.2**, with continual growth in fish production (mostly from aquaculture since the 1990s), increased production efficiency, and improved distribution channels, the world's fish production has increased almost eight times since 1950 (HLPE 2014). Inland aquaculture contributes at least 40 per cent to overall world fish production.

Figure 3.2 World fish production and utilization 1950-2013 (Source: adapted from HLPE 2014)

in design

Livestock production: Livestock is the world's largest user of land resources. In 2013, with almost 3.4 billion hectares, permanent meadows and pastures represented 26 per cent of the global land area (i.e. the earth's ice-free terrestrial surface) (FAOSTAT). The Food and Agriculture Organization (FAO) estimates that between one-third and 40 per cent of global arable land is used to grow feed crops (FAO, global livestock environmental model – GLEAM). Together, permanent meadows, pastures and land dedicated to the production of feed thus represent 80 per cent of total agricultural land.

There are many different systems of livestock production, which enter into the food systems described here in different ways. However, as a general rule of thumb, pastoralist and smallholder livestock raising systems are found in traditional and mixed food systems.

Pastoralist systems are the result of a co-evolutionary process between populations and the environment. They have developed a variety of modes of land tenure and management that are strongly associated with mobility, the use of common pool resources and the ability of animals to convert local vegetation into food and energy. Pastoralism is globally important for the human populations it supports, the food and ecological services it provides, the economic contributions it makes to some of the world's poorest regions, and the civilizations it helps to maintain (Nori and Davies 2007; WISP 2008).

Smallholder systems include "Mixed", "Backyard" and "Intermediate" methods (HLPE 2016). These systems often combine livestock and crops on farm. They are found in all countries throughout the world, but are most heavily concentrated in Asia, Latin America and Africa. The diversified agricultural systems developed by these smallholders are often characterized by the presence of different animals and multipurpose breeds where organic farming and agroecological management integrate holistic systems

Commercial grazing and intensive livestock systems, on the other hand, are integral to modern farming systems.

Commercial grazing systems can be found both in developed and developing countries in areas covered by grasslands, but also in forest frontiers where pastures expand into forests and woodlands such as in the Amazon forest in Brazil. Latin American countries have a small number of commercial farmers who produce the bulk of agricultural production. In some regions, a smaller number of large commercial ranches co-exist with a much larger number of small farms, whereas in other countries such as Brazil, Argentina and Paraguay, large commercial ranches are the predominant land use.

Intensive livestock systems (including "Industrial" and "Feedlot" systems) are most typical in pig and poultry production and are found in all regions of the world, especially in high-income countries and emerging economies. Intensive landless systems are located around urban conglomerates of East and Southeast Asia, Latin America or near the main feed-producing or feed-importing areas of Europe and North America. Concentrated animal feeding operations (CAFOs) globally account for 72 per cent of poultry, 42 per cent of egg and 55 per cent of pork production (Harvey et al. 2017). In

2000, there were an estimated 15 billion livestock in the world, according to the FAOSTAT. By 2016, this figure had risen to about 24 billion, with the majority of the production of eggs, chicken meat and pork taking place on intensive farms (Harvey et al. 2017).

From the standpoint of diversity, however, it has been noted that the majority of vegetables, fish and livestock products (60 per cent), are produced in heterogeneous landscapes, under systems of production that provide a diversity of products and essential nutrients (Herrero et al. 2017)

3.2.5 Typologies of supply chains

Also interwoven into the typologies described above are diverse supply chains, spanning from a simple straight line of firms, strictly guided by the focal company, to a loose bundle of firms interacting via informal relationships and with almost no governance other than market. This section discusses six different chain typologies relevant to the agri-food sector, as seen in **Table 3.2**. Some of these typologies account for very large shares of the worldwide food markets and involve stakeholders, farmers, retailers and consumers. Others represent small market niches and are extremely dynamic.

Supply chains driven by a large retailer are found across the world and hold extremely large shares of total turnover (defined as the amount of revenue earned in a particular period) of the food sector (Carbone 2017). Their massive presence is the result of growth that has taken place at a fast pace during the last decades even in so-called 'emerging economies' and it is still ongoing (Sexton 2012). The retailers that govern the supply chain operate at a large scale and in many cases are multinational global companies.

Supply chains driven by a global processing company have a very well established reputation in final markets and usually govern the food chain in which they operate. They are usually multi-locational, global corporate companies that buy raw materials and other inputs from a large set of farms/firms that are in a quasi-captive position and are connected to the focal company mainly with vertical sequential relations.

Supply chains driven by a cooperative historically play an important role in the organization of food supply worldwide, although their nature and role varies significantly across countries. Cooperatives are themselves hybrid institutions marked by strong and stable horizontal coordination and pooled relationships. These are usually associations of farmers.

Supply chains with geographical indications (names) derive from names for traditional food referring to the location where production takes place. All the producers based in the area are entitled to sell their product with the name of the place of origin. Darjeeling Tea from India and Prosciutto de Parma from Italy are two examples.

Short chains where the focal company is a small farm or processing firm, or even a small-scale retailer, and where there are few transitions for the raw material to reach the final consumer, all mainly confined to the local markets. These are new, yet increasingly common in the modern food sector and common in mixed systems. These chains are essentially demand-driven as they respond to consumers' inclination for simple and local food that is assumed to be more genuine and fresh. Consumers associate short chains with the idea of traceable and transparent processes. Both aspects are seen under a different perspective compared to the previous chains where information is conveyed formally and codified by certifications and standards. Consumers in short chains tend to privilege and prefer face-to-face relationships that are regarded as more reliable and able to foster connections among human beings and add a personal touch to transactions. The growing proliferation of "food hubs", serving to aggregate, distribute and market local produce in the United States, are examples of efforts to create short chains.

Supply chains driven by a specialized high quality retailer are focal companies (generally retailers) that offer high quality food. Their competitive leverage and consumer appeal is the quality and provenance of their products rather than the price or affordability. Sellers offer a rich knowledge of, and intimate relationship with, small and local producers, linking them directly to the consumer (Carbonne 2017). These chains are often characterized by products that might have difficulty competing in larger markets, e.g. local, regional, traditional, ethnic, artisanal, nutritious, organic, fair trade, etc.

Table 3.2 Typologies of supply chains (Source: Carbone 2017).

in design

3.2.6 Spatial and cultural aspects of food systems

Key factors responsible for food system choices are peoples' thoughts around the food they eat and the multiple processes that affect food habits, linked with race, class, health, sexual orientation, social justice and history (Harper 2011). In other words, views around the way food is produced, processed and consumed are directly shaped by the degree of identity we humans connect to these diverse processes and how we link them with a "good quality of life" (Pascual et al. 2017a; IPBES 2014), both as producers and as consumers. Over historic time, genetic resources, but also food and feed, have been transported and exchanged among regions through time, leading to new adoptions, adaptations and uses of crops and animals.

Both of these processes – the evolution of agriculture in distinctly different agroecological zones, and the trade and exchange of agricultural resources and knowledge- have led to high **spatial diversity** in agriculture and food systems, with considerable diversification in the ways cultures around the world value and interact with their food systems. As an example, smallholder rice production systems in much of Asia have been the product of indigenous agricultural innovations and communal decisions and customs. The ancient Subak water management systems developed more than 1000 years ago for paddy rice cultivation on Bali Island, Indonesia are a premium example of this. Subak is a traditional irrigation system that has been adapted over generations to respond to ecological flows as well as cultural imperatives. It does not simply supply water to rice fields according to the ebbs and flows of seasonal rains; it is a cultural service that considers the entire water needs of the community and provides a pulsed provisioning of water to that community. The centrality of rice cultivation, both to food security and in its religious dimensions, is a strong element in many Asian cultures and influences the shape of its food systems (Lansing 2009; Marchi 2012).

The further away societies are from the primary sources of food, the more people may be detached from valuing the chosen ways of food production, processing and distribution, and the more likely they are to lack understanding and appreciation of food systems, leading to serious implications for nature. Today, this is true for a majority of human beings who live in urban areas and have unwittingly detached their reality from their food sources as well as their sense of responsibility for the ways food arrives to their plates. As Pascual et al. (2017a) reemphasized following the IPBES (2014) framework, *"it is critical to acknowledge that the diversity of values of nature and its contributions to people's good quality of life are associated with different cultural and institutional contexts"*. This idea also applies to the existing agricultural models. Closeness and relatedness to food sources provide people with identity and the opportunity to develop an integral understanding of how food is produced and obtained and thus, it creates stronger bonds of identity in relation to the food they eat. By being detached from the food production processes themselves, we humans lose its cultural significance and knowledge and skills developed over centuries.

3.2.7 Temporal aspects of food systems: food regimes and their historical context

Food systems are often understood in a comparative, historically grounded way as food regimes. By definition, food regime is "a rule-governed structure of production and consumption of food on a world scale" (Friedmann 1993). According to McMichael (2009), the food regime concept allows us to refocus from the commodity as an object to the commodity as a relation, with definite geopolitical, social, ecological, and nutritional relations at significant historical moments. Friedmann and McMichael (1989) contend that "international relations of food production and consumption to forms of accumulation broadly distinguish periods of capitalist transformation since 1870". Food regimes are characterized by often contradictory forces of the state, business and social movements to highlight the changing role of agriculture in the development of (capitalist) world economy (Friedmann and McMichael 1989).

Bernstein (2016) defined eight key aspects of food regimes, namely: (i) the international state system, (ii) international divisions of labour and patterns of trade, (iii) the 'rules' and discursive (ideological) legitimations of different food regimes, (iv) relations between agriculture and industry, including technical and environmental change in farming, (v) dominant forms of capital and their modalities of accumulation, (vi) social forces (other than capitals and states), (vii) the tensions and contradictions of specific food regimes, and (viii) transitions between food regimes. These configurations generate stable or consolidated periods (as well as transition periods) of capital accumulation associated with geopolitical power and forms of agricultural production and consumption (McMichael 2009) (see **Box 3.1**).

Box 3.1 A Brief History of Food Regimes (source: Biovision and Global Alliance for the Future of Food 2018)

Emerging frameworks for understanding sustainable food systems are to some extent based on history - where we have been and where we may be going. The Food Regime Theory of Friedmann and McMichael (1989) traces the legacies of previous "food regimes" – starting with those from the late 1800s to 1930 in which family labour and its contribution to export agriculture underwrote the growth of food markets and nation-state systems. The period of 1950 to the 1970s witnessed a second regime comprised of the extension of the state system to former colonies, and the restructuring of the agricultural sector by agri-food forces. The authors suggest that two complementary alternatives are now possible choices to transform food systems: (1) global institutions capable of regulation of accumulation, and (2) the promotion and redirection of regional, local and municipal politics deriving from decentralized ideologies. More recent articulations of the current "food regime" (McMichael 2009) continue to note the inherent contradictions as corporate food regimes embrace environmental dimensions, with the risks that "green capitalism" fosters new forms of accumulation by appropriating the demands of environmental movements. The key counterweights to such accumulations of power are seen as social movements, such as Food Sovereignty or Fair Trade Movements and others from the Global South. These perspectives demand that we address the "externalities" in food regimes, "embracing a holistic understanding of agriculture that dispenses with the society/nature binary, and politicizes food system cultures" (Friedmann and McMichael 1989).

3.3 CHALLENGES AHEAD FOR THE WORLD'S AGRICULTURE AND FOOD SYSTEMS

Various external forces and "lock-ins" reinforce forms of food production that neglect the contribution or negatively impact nature and harm human welfare. The impacts include widespread degradation of land, water and ecosystems; high greenhouse gas emissions; major contributions to biodiversity losses; chronic over and under malnutrition and diet-related diseases; and livelihood stresses for farmers around the world (IPES-Food 2016).

In this section, we will look at economic pressures and external forces that pose challenges to sustainable agriculture, and then explore pathways to viable solutions. Throughout, we will seek to highlight those invisible and visible flows in the food system that are the focus of the TEEB perspective.

Too often the analysis of agricultural systems focuses on production while paying far less attention to subsequent steps such as transformation, transportation, distribution, consumption and recycling. This is a serious problem since most of the economic benefits are concentrated in the stages after biomass production. The segmented approach also does not allow an analysis of materials and energies used in the food chain, and the interactions between them. The TEEBAgriFood Evaluation Framework, this chapter, and other sections of this report address the different value-chain stages, incorporating the visible and invisible flows of different indicators (quality and quantity indicators).

3.3.1 Economic pressures and external forces around agricultural and food systems transitions

Models of agricultural development: For many decades, developing countries have been encouraged to follow the path of industrialized countries by undergoing a "structural transformation" from having large, low-productivity traditional agricultural sectors to more industrialised agricultural sectors as a precursor to a modern industrial economy with high productivity (Byerlee et al. 2009) and an expanded service sector (Dorin 2017). More recent models consider agriculture not merely as the facilitator of industrialization but as central to development itself. Nonetheless, productivity remains central to the predominant economic models for growth and development, fed by increases in land and labour productivity in agriculture. Tensions in this model are apparent in many regions. For example, the majority of African countries have limited arable land resources with high population pressures. Yet most projections for substantial yield increases earmark African countries as the locale where these increases are most needed. Current yield gaps in Africa are both pervasive and complex, with clear biophysical limitations but also issues that call for greater attention to social contexts (Tittonell and Giller 2013; Mapfumo et al. 2015), diversification and infrastructure investment (Van Ittersum et al. 2016). Large-scale land purchasing by foreign investors or "land-grabbing" is also a problem in Africa (UNEP 2014). Thus, both land and labour are under conflicting economic pressures in the agriculture sector, as we review below.

Labour and employment in the food and agriculture sector: The agricultural sector employs one out of every three economically active workers (FAO 2014). **Figure 3.3** shows that, as countries develop, the share of the population working in agriculture declines. While more than two-thirds of the population in poor countries work in agriculture, this percentage decreases to less than 5 per cent in rich countries (Roser 2018).

In developing countries, labour in the agricultural sector is a key area of focus for current and future economies. There are 1.5 billion smallholder farmers, and an estimated 500 million family farms, i.e. those that are managed and operated by a family and predominantly reliant on family labour globally (FAO 2014). These family farms make up more than 98 per cent of the world´s farms (Graeub et al. 2016).

With this in mind, new voices are suggesting that the "structural transformation" trajectory is not and will not be a reality in much of the developing world (Dorin 2017). As has been true in India, it is highly plausible that the rural population and labour force in agriculture in Africa (and India) can be expected to remain massive through the next few decades. These findings require a reconsideration of the "modern" model of increasing land and labour productivity in agriculture. In view of the size of the rural labour force, it has been argued that increases in agriculture in these regions should not rest on large scale monocultures and intensive use of inputs, but rather on a context-specific agroecosystems that build biological synergies and boost biodiversity and ecological functions to increase and sustain productive growth in multiple dimensions, delivering multitude of long-term benefits (Dorin 2017). Certainly, finding sustainable means to increase access, availability, utilization and stability of food is critical to both avoiding deforestation and addressing food security in many developing countries.

An overriding challenge and concern in developing and developed countries alike is the eroding profitability of farms, with farming professions ceasing to provide a living wage and viable livelihoods within rural communities. As noted by Buttel (2007) the practice of farming has for many decades been in the grips of a "profitability squeeze", undermining social, economic and environmental sustainability. In developed countries such as the US, net farm incomes have declined consistently and dramatically since 1948, a trend that has to some degree been lessened in severity through the application of subsidies. Such resources and public policies are not available to lessen the severity of declining and volatile profitability in agriculture for farmers and communities in developing countries.

Figure 3.3 Relationship between participation in agricultural sector and GDP per capita in several countries, in 2015. (Source: adapted from Roser 2018)

in design

Investment and land demand and supply: Altogether, worldwide foreign direct investment in agriculture has increased significantly since 2000, especially in developing countries, reaching more than 3 billion USD per year since 2005 (UNCTAD 2009). However, global foreign direct investment flows lost growth momentum in 2016, showing that the road to recovery remains bumpy (UNCTAD 2017). FDI inflows decreased by 2 per cent to $1.75 trillion in 2017, amid weak economic growth and significant policy risks, as perceived by multinational enterprises (UNCTAD 2017). Agriculture and food systems have been particularly impacted by land grabbing, the large-scale land acquisition—be it purchase or lease—for agricultural production by foreign investors. In the three years from 2007 to 2010 for example, more than 20 Mha are thought to have been acquired by foreign interests in Africa (Hallam 2010). Several countries are now changing rules for direct foregoing investors. Argentina eased certain restrictions on the acquisition and leasing of rural lands by foreign individuals and legal entities. Malawi lifted a ban on oil and gas exploration in Lake Malawi. Myanmar introduced the new Condominium Law, permitting foreigners to own up to 40 per cent of a condominium building. Poland adopted new restrictions for the acquisition of agricultural and forest land and for purchasing shares in Polish companies that have agricultural property (UNCTAD 2017). The discussion of foreign investment in and purchase of land is on the table and is generating deeper consideration of benefits and costs.

While the concept of acquiring land abroad to pursue economic interests is not new, this new type of land grabbing may also lead to violations of human rights (Rosset 2011) and environmental consequences which directly counteract the commitments of countries made to eradicate such occurrences (as in the case of the Millennium Development Goals). Early experiences with biofuel production in countries like Tanzania, Mozambique, India and Colombia have been characterized by land purchases marked by illegitimate land titles, water access denied to local farmers, inadequate compensation agreements, and displacement of local communities by force (Cotula et al. 2008; Cotula et al. 2009). In Argentina, 14 million hectares have been sold with consequences for rural peasants, indigenous people and even completed towns that have been sold to individuals or companies (Pengue 2008). Such projects often do little to improve regional food or energy security. Because of the industrial, high-tech agriculture that land grabbing favours, it often means a step backward for peasants or small farmers and sustainable agriculture. This contradicts authoritative international recommendations, which see the support of smallholder agriculture as a fundamental effort in the struggle against hunger (UN Human Rights Council 2010). Displacing local producers and diverting resources to cash crop production may increase the vulnerability of local communities to the volatility of food prices.

Investment in biofuel and biomass: Investment in the biomass sector is a growing issue, increasing the demand for land practically all over the world. This demand is not only related to food production but also includes demand related to animal feed, biomass, biomaterials and others. As the intention of biofuel projects is to later export the fuel, this does little to substantially improve the energy situation in the country of production. For instance, roughly two-thirds of Mozambique is without electricity, but even projects intending to keep 20 per cent of the ethanol produced within the country are unlikely to contribute to the amount of electrification needed to improve living conditions (FIAN 2010).

Subsidies and distorting fiscal measures along the value chain: Due to the rapidly increasing productivity in major OECD countries in particular, the 1970s and 1980s were characterized by domestic overproduction of food, resulting in domestic surpluses. The subsidized export of these surpluses tended to depress world prices, affecting agriculture production in other countries. Distortions in global markets reached a peak in the 1980s, with overproduction of food in the European Union (EU) and an export/subsidy war between the United States of America (USA) and the EU further depressing agricultural prices in low- and middle-income markets (UNEP 2016), thereby affecting millions of farmers in developing countries and their markets. Despite these negative impacts, OECD countries have continued to pursue policy measures that promote the intensification and overproduction of food commodities, and the liberalization of trade to facilitate export to more vulnerable developing economies.

Distortions in global markets create social, economic and environmental impacts. Some discussion of the nature of current subsidies in the agriculture sector is provided here, while recognizing that the subject is complex and the analysis of impacts is very challenging. By way of a simplified explanation, perverse subsidies tend to create distortions in the global market and can lead to more overexploitation of natural resources and human resources. Globally, the tendency for subsidies to encourage the intensification of production at the cost of the environment (negative externalities) has been noted, but largely ignored. If global farm subsidies were ended and agricultural markets deregulated, different crops would be planted, land usage would change, and some farm businesses would contract while others would expand (Edwards 2016). Where subsidies are underwriting farming with highly negative externalities, the withdrawal of this support would result in different crops being planted, land usage changing away from such systems, and some farm businesses contracting while others would expand. The absence of deleterious subsidies could contribute to a stronger and more innovative industry. New relationships in the food system could emerge that have greater resilience to market fluctuations (Edwards 2016). Private insurance, other financial tools, diversification, and payments to farmers to recognize their role in protecting the environment could help cover risks, as they do in other industries and small and midsized farmers and peasants would find a clearer connection between their labour and prices and a greater recognition of their efforts.

Consolidation in the food sector: A number of external forces have increasingly impacted global food systems in recent decades. The introduction of neo-liberal modes of governance, globalization, de-regulation, privatization, the establishment of WTO rules for agriculture, and the increase in the size and influence of financial institutions have all contributed to the dismantling of the state-centred national agricultural development models (Barker 2007). These have been supplanted by privatized agricultural systems (marked, for example, by the dismantling of state marketing boards), structured to service global markets and rapidly expanding trade (Barker 2007). At the same time, the information technology revolution has transformed logistics, leading to the expansion of globally traded foodstuffs, fertilizers and pesticides possible on scales that would have been unimaginable in the mid-20th century. The biotechnology industry has enabled the commercialization of genetically modified organisms (GMOs) with strong proprietary rights. As a result of these developments, an unprecedented level of consolidation is occurring in the food sector globally (IPES-Food 2017).

Since the elimination of most public commodity stock-holding programmes in big exporter countries – Argentina, Canada, New Zealand, including the USA and the EU (a gradual process that started in the 1980s) – the international firms involved have themselves begun to hold more physical stocks. The existence and control of these physical stocks can have an important impact on grain prices, and information about them is likely to be very important in guiding these firms with respect to their financial investments in agricultural derivatives markets. In this way, the storage function of the large global agribusiness firms is tightly integrated with other aspects of their business activities.

Trade in any commodity is characterized by risk. Any number of factors – natural disasters, crop failures, political or economic shifts, market speculations – can affect the prices of agricultural commodities, which may be locked into a long supply chain. While prices can change quickly, commodity traders are dealing with a physical stock that is bulky, expensive to store, and harvested only at certain periods of the year. Prices are as much about anticipated supply and demand as they are about existing conditions. The level of risk and volatility in the trading of standardized and generic products pushes the companies to look for strategies that will increase their stability and predictability.

Overall, the period of high prices and high volatility appears to have served financial interests of the large global agribusiness firms well, though they have lost money in some areas too, and all suffered in 2009 following the financial crisis and the collapse in international trade. Disruptions to commodity markets in 2010, including the Russian export ban, created opportunities for grain trading firms to profit from food price shifts (Murphy et al. 2012).

International trade and trade policies: International trade and trade policies affect the domestic availability and prices of goods and also affect factors of production such as labour, with implications for food access. International trade can also impact market structure, productivity, sustainability of resource use and nutrition among various population groups in different ways. Assessing trade's impact on food security is thus highly complex.

For example, banning grain exports can boost domestic supplies and reduce prices in the short run. This benefits consumers, but has negative implications for farmers producing for export. Import or export restrictions by major players affect global supplies and exacerbate price volatility at the global level. Lowering import duties reduces food prices paid by consumers, but can put pressure on the incomes of import-competing farmers, whose own food security may be negatively affected (see **Table 3.3**). Policies to increase openness to international trade have generally taken place in the context of wider economic reforms, and it is therefore difficult to disentangle their effects.

Table 3.3 The possible effects of trade liberalization on dimensions of food security (Source: adapted from FAO 2015a)

in design

Financialization of the food system entered a speculative mode beginning in the 1990s, when the deregulation of commodity futures trading in the United States made it possible for institutional investors to enter this market on a large scale. Since then, on the world's most important futures exchange CBOT in Chicago, the percentage of commercial traders has decreased remarkably, while the number of speculative traders has exploded. In 2002, eleven times the actual amount of wheat available was traded on the CBOT; in 2011, 73 times the actual US wheat harvest was traded (Global Agriculture 2017). Although these speculative deals in food commodities are generally oriented towards the real situation of supply and demand, the psychology of the stock exchange and the algorithms of the computers that control the trade have led to increasingly nervous fluctuations. According to many analysts, the investors who bet on long-term increases in food prices are now having a price-driving effect (Global Agriculture 2017).

A handful of global corporations now organize the world's agriculture and food-consumption patterns. They are remarkably long-lived: many of today's leaders were founders of the modern agri-food system. This has led to two major developments – a shift towards finance capital and the impact of biotechnologies – that have led to a wave of mergers and acquisitions since the 1980s, changing the face of the sector and transforming financing in agriculture (HBF 2017).

3.3.2 Responses to economic pressures and external forces in global agriculture and food systems

The economic pressures and external forces described above have exerted significant changes, especially over the past fifty or so years, on the nature of food and farming. In this subsection, we will highlight these challenges, which impact production systems and the global environment (as well as nutrition and human welfare, which are featured in subsequent chapters of this report).

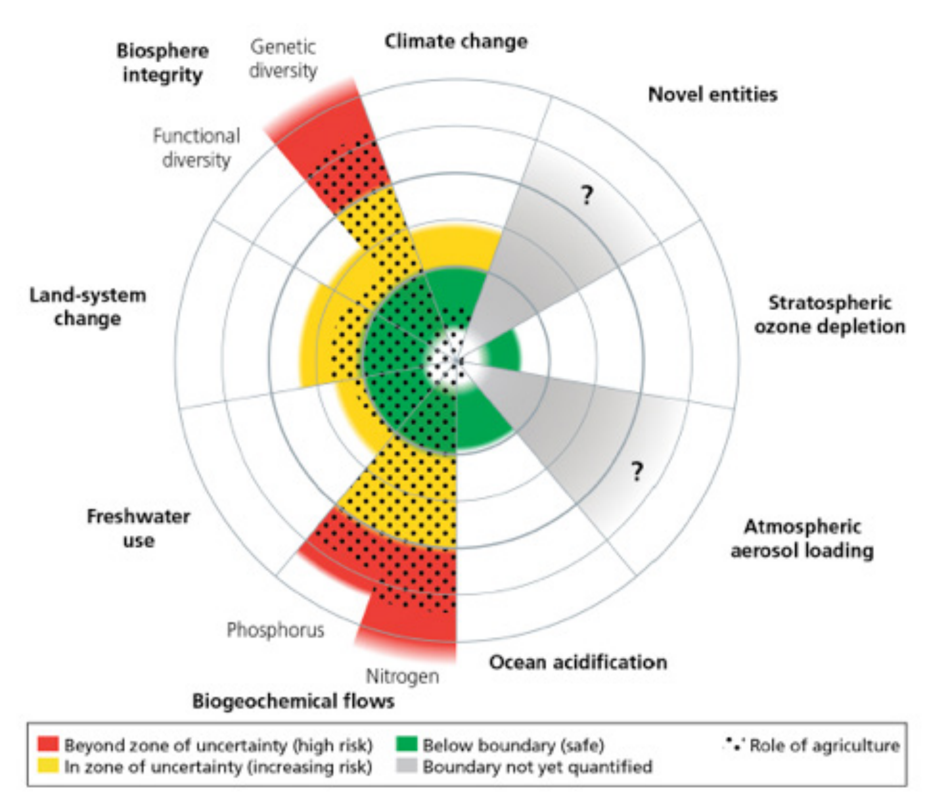
Move away from use of renewable resources: Human domination of the terrestrial space has grown enormously, to the point that agricultural systems occupy much of the geographic space available to produce biomass to sustain flora, fauna and human populations. Croplands and pastures are estimated to be one of the largest terrestrial biomes on the planet, occupying~40 per cent of land surface (Foley et al. 2005), making agricultural production the planet's single most extensive form of land use (Campbell et al. 2017).

Agriculture is inherently a resource-intensive enterprise (Campbell et al. 2017). As agriculture has expanded in land area, so has its environmental impact. Figure 3.4 shows that, in multiple dimensions, agriculture is contributing substantially to destabilizing key Earth processes at the planetary scale: land-system change, biosphere integrity, biogeochemical flows, biosphere integrity, and freshwater use have all been impacted to some degree (ibid) Currently, degradation of the Earth's land surface through human activities is negatively impacting the well-being of at least 3.2 billion people, pushing the planet towards a sixth mass species extinction, and costing more than 10 per cent of the annual global gross product in loss of biodiversity and ecosystem services (IPBES 2018a).

To a large extent, these destabilizing forces have arisen as agriculture has increasingly moved away from its dependence on natural processes and renewable resources towards non-renewable resources. For example, biogeochemical flows have been profoundly transformed as farming systems have discarded traditional means of maintaining soil fertility (through fallowing, integrating livestock with crops, and use of composted material) in favour of increased use of fossil-fuel-based and mined fertilizers. Similarly, stratospheric ozone depletion is linked to increasing rates of N2O emissions (associated with nitrogen fertilizer application and manure from confined livestock operations). Concentrations of half the pesticides detected in freshwater aquatic systems currently exceed regulatory thresholds, a consequence of the high dependence in many agricultural systems on agrochemicals rather than natural pest control (Campbell et al. 2017). The tremendous increases in productivity over the last half century, propelled by the external forces of international markets and competition over land among others, have come with a number of costs, including stability and consistency of food security for many stakeholders.

Current trajectories have been driven by imperatives to increase both efficiency and productivity. Many observers note that there is an equal imperative to reduce the environmental impacts of these trajectories. Given the need to simultaneously address productivity, sustainability and equity, solutions will be complex.

Figure 3.4 The status of the nine planetary boundaries overlaid with an estimate of agriculture's role in that status (Source: Campbell *et al.* 2017)



Recent analyses of agricultural and environmental trends suggest that the environmental footprint of agriculture can most effectively be addressed by avoiding further expansion into natural ecosystems, increasing the efficiency of inputs, and improving soil health (Clark and Tilman 2017). Of these, reducing expansion into natural ecosystems seems imminently possible, given that agricultural production in developing countries has increased by about 3.3 per cent per year over the last two decades, while agricultural land area increases due to deforestation have been on a much smaller order, of .3 per cent (Angelsen 2010), reversing earlier trends (Gibbs et al. 2010). At the same time, it should be noted that these positive global trends mask differences between tropical deforestation, which has accelerated since the 1990s while temperate forest cover has remained stable or grown (Kim et al. 2015), pointing to the need to address all approaches simultaneously. Approaches to improve input efficiencies and build soil health are measures that build on ecosystem services, of great relevance to this report (see section 3.4.1 on the interdependence of nature and agriculture).

The impact of loss of connections to local communities: Agricultural systems have also lost many of their connections to local communities, as they have become - in some regions - monocultures oriented to external markets through the purchase of industrial inputs to sell commodities for profit (FIAN 2009). Many modern agricultural systems have ceased to use local labour, and dispensed with the benefits received from biodiverse landscapes, creating a loss of regional environmental services. Resulting problems such as deforestation, soil erosion, biological species loss, toxic contamination, greenhouse gas emissions, and rural migration have arisen.

Impacts of food prices on the dynamics of food systems: The dynamics of food systems are a complex issue, strongly influenced by market and international prices. Food prices in turn are driven by a complex combination of factors. The investment of international capital in food and agriculture has major implications for the distribution and cost of food. Financial institutions and instruments have become increasingly involved at all points of the agri-food system. When average prices of (food) commodities increase, this gives rise to growing speculation (e.g. by trading of futures) (UNEP 2014), which may also result in price spikes. Fluctuating prices are a core problem for stable food production. Agricultural price volatility increases the uncertainty faced by farmers and affects their investment decisions, productivity and income. Instability in prices is a complex factor in the agricultural domain as well as in biomass processing and consuming sectors.

The markets around biomass can serve as an example. Biomass– defined as energy obtained by burning wood or other organic matter – has been a part of human societies for millennia. But recently biomass has become an internationally traded commodity for use not only as food and feed in agroindustry, but also as biofuels and biomaterials. The growing demand for food, feed and fibre exerts additional pressure on suppliers and consumers through higher level and volatility of prices, compromising food security (in particular for the poor, as happened in 2008). Growing prices of food and non-food biomass render productive land a more precious asset and have encouraged private and state investors to realize larger land purchases in low cost countries with often less favourable social and environmental controls.

Consumer behaviour, changing diets and new trends: The combination of rising income and urbanization is changing the nature of diets (Msangi and Rosegrant 2009) and thus food systems. While the consequences are dealt with in more detail in section 3.3.7, here we outline the major trends and pressures in both urbanization and diet changes.

Urbanized populations consume less basic staples and more processed foods and livestock products (Rosegrant et al. 2001). This implies more potatoes for fast food, more oilseeds for feed and more sugar for food processing and manufacturing (Fischer et al. 2009; OECD-FAO 2010). UNEP (2013) predicts that 4 billion more urban dwellers will live in developing world cities between 1950 and 2030, in what might be considered a "second wave of urbanization". This "wave" noin w underway promotes a major transformation of demand for environmental, natural resources and ecosystem services from urban areas. Processed, prepared foods may require a higher use of agricultural commodities to create a given number of calories (von Witzke and Noleppa 2010), and meat consumption requires pastures for grazing and cropland for growing feed. The expansion of agricultural land has happened at the expense of natural ecosystems.

Projections on food production (both calories and nutrition) increases needed over the next several decades are often contested (Meyfroidt 2017), although a few key points are emerging around which there is a fair amount of agreement. The productionist argument, that the amount of food produced globally will need to double (Tilman et al. 2011), or increase by 70 per cent (FAO 2009), or by 60 per cent (Alexandratos and Bruinsma 2012) has been tempered by the realization that clean water and sanitation, and female education have been responsible for 68 per cent of the reduction in child malnutrition (between 1970 and 2010 in a longitudinal study across 116 countries), while increased food supply accounted for only around 18 per cent (Smith and Haddad 2015). A recent parsing (Chappell 2018) lays out the logic to suggest that we currently produce almost enough food on a calorie basis for the estimated 9.14 billion people projected for 2050, even with no changes to diet or waste. Thus, meeting global needs in the future might best focus on changes in production systems that might conceivably slightly reduce yields in some regions to favour environmental benefits, but more generally address yield gaps through ecosystem services while focusing on diets and reducing food waste. Increasingly, the focus is on the nutritional quality of food produced, noting that the spectacular production increases of the last half-century have come from high-yielding and not nutrient-dense cereals, such that more food needs to be consumed to attain recommended dietary levels for many nutrients than in the past (DeFries et al. 2015).

Much of the structural change in diets is occurring in developing countries, as diets in developed countries are already high in processed foods and livestock products. For instance, the three food groups of livestock products (meat, milk, eggs), vegetable oils and sugar currently provide around 29 per cent of total food consumption in developing countries (in terms of calories). If current trends continue, their share is projected to rise to 35 per cent in 2030 and 37 per cent in 2050, whereas their share in industrial countries has been around 48 per cent for several decades (Alexandratos and Bruinsma 2012). In 2008, 80 kg per capita of meat was consumed in developed countries in 2008, compared to 29 kg in developing countries (Alexandratos 2009). Projections for 2050 carrying forward current trends expected an increase to 103 kg in the former and 44 kg in the latter (FAO 2006). However, a more recent revision of these estimates suggests that not all developing countries – such as India – will shift in the near future to levels of meat consumption typical of western diets, and thus the estimates of how much the growth of world food production will be required to increase to meet demands have been revised downward (Alexandratos and Bruinsma 2012).

Altogether, the projections for world food consumption predict an increase of about 10 per cent in the global average caloric intake per person from 2005 to 2050, along with projected increases in population numbers. In 2009, around 5 per cent of the population was still expected to be chronically undernourished by 2050 (Alexandratos 2009); three years later this figure was modestly revised to estimate 4 per cent of the population (Alexandratos and Bruinsma 2012). Bruinsma (2009) has forecast an increase of 71 Mha of arable land needed to meet these rising food and feed demands. A 12 per cent expansion is predicted in developing countries, especially in sub-Saharan Africa (64 Mha) and Latin America (52 Mha), whereas a 6 per cent decline is expected for developed countries. While Fischer et al. (2009) also forecasts a 12 per cent increase in cultivated land in developing countries, he estimates an overall increase of about 124 Mha between 2010 and 2050. Neither scenario considers biofuels, biomaterials and changing demands from other industries.

Changing diets implies a shift from vegetable protein to animal protein. This "battle for the protein" (plant-based foods vs. animal-based foods) is changing the face of the earth (Pengue 2005). If current trajectories continue, a more diverse food production model will be replaced by the extensive cultivation of feed crops for animals, largely destined for Europe and China. As a result, poor people will no longer produce or be able to afford the diverse diets they once enjoyed: traditional diets with reasonable portions of high value meat protein grown on less intensive pasture will increasingly be displaced by cash crops such as soybean (Rosin et al. 2013) destined for animal feed.

3.3.3 Externalities and invisibles: Global costs of global food trade

For centuries, countries have relied on trade in agricultural and food commodities to supplement and complement their domestic production. The uneven distribution of land resources and the influence of climatic zones on the ability to raise plants and animals have led to trade between and within continents.

Trade, in itself, is neither a threat nor a panacea when it comes to food security, but it can pose challenges and risks that need to be considered in policy decision-making. To ensure that countries' food security and development needs are addressed in a consistent and systematic manner, policy makers need to have a better overview of all the policy instruments available to them and the flexibility to apply the most effective policy mix for achieving their goals (FAO 2015a).

Moreover, the hidden costs of the global food trade are largely not known or recognized by policy makers. It is such externalities and invisibles that are a focus of true cost accounting in agriculture and food, and thus this report.

Externalities generally refer to the social or economic costs that are not recognized within financial transactions. Externalities, defined as *"a positive or negative consequence of an economic activity or transaction that affects other parties without this being reflected in the cost price of the goods or services transacted"* These may be either negative (such as pollution by nitrogen run-off from crops) or positive, such as the pollination of surrounding crops by bees kept for honey.

Several of the externalities in the agriculture sector are directly related to international trade in agricultural and food production. Agriculture and food consumption are identified as one of the most important sources of negative externalities, creating serious environmental pressures on natural habitats, land use change, climate, water use and air quality (UNEP 2010).

As international trade in food and feed products has increased, insidious forms of visible, and invisible, flows are occurring. For each shipment of food being transported from one part of the world to another, the natural resources used in the production of each shipment is also, in a sense, being "virtually" transferred to the recipient country. Essentially, the evolution of international trade has facilitated the transfer of resources from the centres of supply to the centres of demand. The inequities involved in such transfers have been noted. An "Ecological Prebisch" analysis (as articulated in Pérez-Rincón 2006) follows on the thesis of the famous economist Prebisch, that the gains of international trade and specialization have not been equitably distributed and that in the current century there is an unequal international ecological exchange (natural resources/environmental services/ecological impacts) in the global trade matrix.

These same dynamics are identified in the concept of "off-stage" ecosystem service burdens, recognizing that many place-based analyses ecosystem assessments overlook the distant, diffuse and delayed impacts of current economic systems, including the increased reliance on final and embedded imports and exports of natural resources in the sectors of food and fisheries (Pascual et al. 2017b; Liu et al. 2013), particularly through the commodity supply chains of high income and high price-elasticity crops (Meyfroidt 2017).

As a result of these analyses, indicators such as "material footprint", "water footprint" or "nutrients footprint", have emerged and allow the characterization of material (or carbon, or water, or land and soils) consumption levels of individual countries, including the upstream flows used to produce respective imports and exports (Hoekstra and Wiedmann 2014; Tukker et al. 2014; Wiedmann et al. 2015). These upstream material requirements are also known as, 'materials embodied in trade', 'indirect flows', 'hidden flows', 'virtual flows' or 'ecological rucksacks'. Indicators for upstream resource requirements should capture resource use along the production chain and allocate environmental burden to the place of consumption. Beyond directly traded masses, upstream flows provide insights into the overall physical dimension of trade.

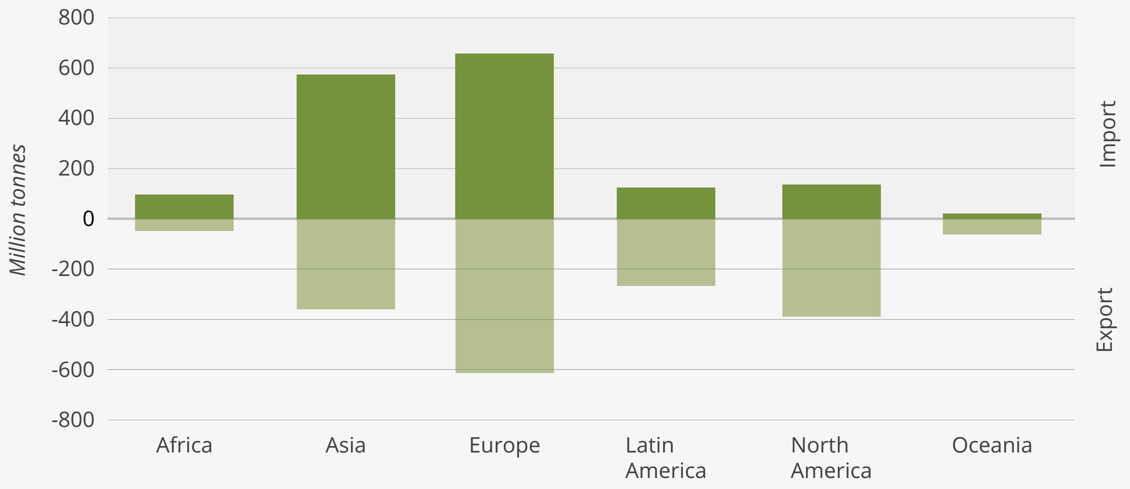
Biomass: Biomass can serve as a case in point. In 1900, biomass was still the major resource used by societies, as a source of nutrition as well as for construction and energy provision (Dittrich 2012). Global biomass use stood at 5 billion tons in 1900 (Krausmann et al. 2009), which represented 75 per cent of all material use. By 2010, biomass trade had increased to 21 billion tons.

Overall, around 15 per cent of all biomass materials globally extracted are redistributed through foreign trade (UNEP 2015). Biomass materials are homogeneous in terms of their chemical composition [hydrocarbons] but still comprise different materials. The major share of biomass use comprises crops (36 per cent, cereals, vegetables, roots, fruits, etc.) and crop residues (20 per cent, mainly straw and beet leaves), followed by fodder crops (6 per cent), grazed biomass (26 per cent) and timber (11 per cent). Fish catch is relatively small, compared to total biomass extraction, amounting to only 0.4 per cent (UNEP 2015). **Figure 3.5** and **Figure 3.6** show the extent of trade by commodity and by country, respectively.

Figure 3.5 Trade in biomass by main sub-category, 1980-2010 (Source: Dittrich 2012)

in design

Figure 3.6 Biomass-based commodity trade between countries (Source: Dittrich 2012)

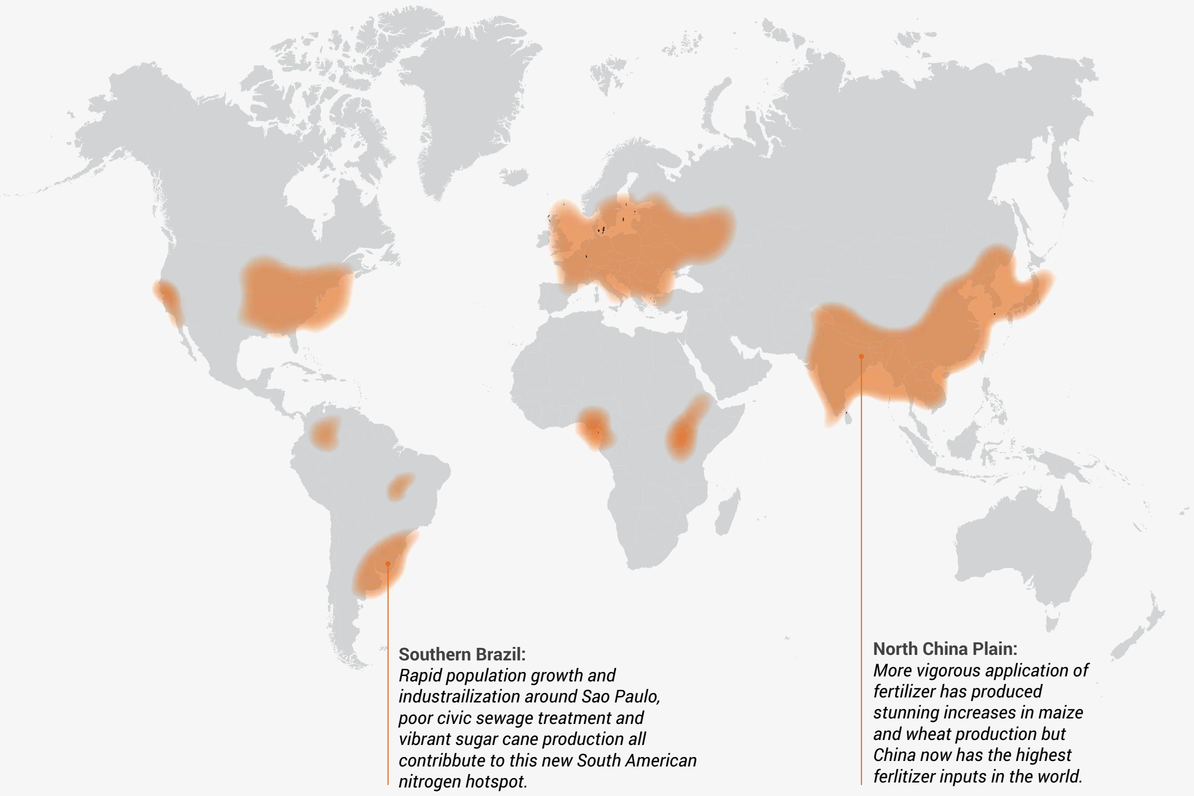


As biomass is transported in large volumes across the world, the underlying agricultural production acts like a "mining" process in several parts of the world. Biomass production requires large amounts of the nutrients N, P and K, amongst other nutrients (oligo and micronutrients), to provide the building blocks of all plant and animal life. Countries with substantial farming activities tend to use intensified farming practices, which extract nutrients from soils. To balance this, modern conventional farming enterprises generally increase the use of NPK inputs in fertilizers (Liu et al. 2010). If nutrients are not replenished, then soils become depleted and plant growth is restricted. This soil exhaustion represents a 'hidden cost' or environmental intangible (Pengue 2009), since nutrients exported from soils as natural capital remains unaccounted for (Díaz de Astarloa and Pengue 2018). Agricultural intensification and mining soils, carried out without regenerative practices, accumulates disturbances over time, putting millions of hectares under the possibility of a collapse via nutrient degradation and soil erosion. Mining agriculture is reducing soil, fauna and root diversity, causing replacement of native species by invasive species of invertebrates, fungi and other important biological components of the soil, homogenizing the agroecosystem, simplifying landscape structure and increasing the occurrence of bioinvasions (Binimelis et al. 2009; FAO 2011a). This means degradation in the quality of these lands that are on the producing end of biomass transfers globally.

Figure 3.7 Regions of greatest nitrogen use in the world (adapted from Townsend and Howarth 2010)

Shifting hotspots

Regions of greatest nitrogen use were once limited mainly to Europe and North America. But as new economies develop and agricultural trends shift, patterns in the distribution of nitrogen are changing rapidly. Recent growth rates in nitrogen use are now much higher in Asia and in Latin America, whereas other regions -including much of Africa- suffer from fertilizer shortages.



Southern Brazil:
Rapid population growth and industrailization around Sao Paulo, poor civic sewage treatment and vibrant sugar cane production all contribbute to this new South American nitrogen hotspot.

North China Plain:
More vigorous application of fertilizer has produced stunning increases in maize and wheat production but China now has the highest ferlitizer inputs in the world.

Changes in nutrient flows and concentrations: Changes in nutrient concentrations globally can also serve as an example of externalities and invisibles in global trade. Under the current agricultural and food trade at international level, the issue of nutrients flow is a relevant point, especially in terms of the environmental, agronomical and socioeconomic effects that the situation generates. While many modern agricultural activities - as well as traditional and mixed farming methods pushed to the limit by population and market pressure - are causing nutrient depletion, erosion and degradation in exporting territories (Styger et al. 2007; Tittonell and Giller 2013), in the importing territories of these grains, nutrient pollution is one of the main issues as a result of accumulation (Halberg et al. 2006).

Nutrient concentration in several regions of the world (see **Figure 3.7**) as a result of agriculture's increased biomass production and consumption is producing a nitrogen and phosphorous cascade with environmental and social impacts. As Townsend and Howarth (2010) indicate, the regions of greatest nitrogen use were once limited mainly to Europe and North America. However, as new economies develop, and agricultural trends shift, patterns in the distribution of nitrogen are changing rapidly. Recent growth rates in nitrogen use are now much higher in Asia and in Latin America, whereas other regions—including much of Africa—suffer from depletion of nutrients in soils.

Continual increases in beef production lead to surges in nutrients flow (Townsend and Howarth 2010; Chemnitz and Becheva 2014). The demand for grain for cattle feed, and thus the intensive production of corn and soy in the American Midwest along with Brazil, Paraguay and Argentina has far reaching impacts. Such high levels of production are often only made possible by a production system equally high in inputs. Yet the application of agricultural chemicals to annual row crops is extremely "leaky"; it is estimated that less than 15 per cent of phosphorous, and 40 per cent of the nitrogen applied to crops is actually absorbed by the plants; the rest remains either in soils or in waterways each year, contributing to the over 400 oceanic dead zones (Zielinski 2014). This dynamic is variable, depending on soil characteristics and other environmental conditions, but remains problematic in the regions of greatest animal feed production.

Figure 3.8 Generalized representation of N transfers through the world agro-food system in 1961 and 2009 (Source: Lassaletta *et al.* 2016)

in design

Invisible flows in nutrients are also due to disconnects in production systems, across borders and continents. The international trade of food and feed products has profoundly affected the flows of nitrogen in the form of vegetable or animal protein between continents over the last fifty years (see **Figure 3.8**). Generalized representation of N transfers through the world agro-food system in 1961 and 2009). The largest component of traded agricultural commodities is animal feed, which enters international trade primarily from countries producing feedstuffs to countries where the proportion of meat in the human diet is high or rapidly increasing (Kastner et al. 2012), and which have intensive animal production facilities. This disconnect between crop and livestock production between countries and usually continents results in the inability to close nutrient cycles, thus causing nitrogen surpluses and inefficient use of nitrogen (Billen et al. 2015, Lassaletta et al. 2016). The large N surpluses are lost to the environment via surface runoff, leaching to ground and surface water, and gaseous emission, all representing large costs to society (van Grinsven et al. 2013; Sobota et al. 2015).

Virtual water: The concept of virtual or embedded water (Mekonnen and Hoekstra 2011) was first developed as a way to understand how water-scarce countries could provide food, clothing and other water intensive goods to their inhabitants. The global trade in goods has allowed countries with limited water resources to rely on the water resources in other countries to meet the needs of their inhabitants. As food and other products are traded internationally, their water footprint follows them in the form of virtual water. This allows us to link the water footprint of production to the water footprint of consumption in any location. The analysis of "virtual water flows" help us see how the water resources in one country are used to support consumption in another country. The largest virtual water exporters are in North and South America (Dalin et al. 2012). Virtual water flow between the six regions in Figure 3.9 remained somewhat similar in patterns between 1986 and 2007, but with large changes in volumes. South America, as can be seen, increased its participation in the international trade of virtual water, while Asia converted into one of the main importers (see **Figure 3.9**).

Figure 3.9 Virtual water flows between the six world regions (Source: Dalin *et al.* 2012)

in design

Figure 3.10 Trade balances of virtual land for the EU-27 (Source: UNEP 2015)

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Virtual land: In the case of land, the terms of embodied land or intangible land are directly related to the ecological footprint concept (Costello et al. 2011; Steen-Olsen et al. 2012; Weinzettel et al. 2013; Yu et al. 2013). The concept recognizes that some agricultural and forest products – such as cattle, biofuels and forest products – are especially land-demanding. The consumption of these products remains high in certain regions, such as the US. Costello et al. (2011) concluded that the US was a net importer of embodied land, especially forest area. Similar studies exist for the European Union; these studies establish that the cropland demand in the EU linked to consumption in the region (estimated at .3 ha/cap) is larger than the EU's present cropland area (.25 ha/cap (Bringezu et al. 2012). Figure 3.10 presents the relationship between EU and the world in terms of virtual land imported (UNEP 2015).

Virtual soils: Virtual soils (Pengue 2010; UNEP 2014) relate to the nutrient footprint in terms of intangibles that are incorporated in the grains, meat, wood, milk and other exports of biomass, and the export of nutrients extracted from the soils (see Box 3.2) where they are produced to the places where the grains and food are consumed. Using Denmark as an example, it was shown through a Life Cycle Analysis (see more on this method in Chapter 7) that the international flow of nutrients between producer and consumer countries (soybean in Latin America/pig production in Denmark) causes depletion of soils in the origin country and contamination in the reception country (Dalgaard et al. 2008). This has clear relevance for the ways in which the agriculture sector, in terms of nutrients, is contributing to exceeding planetary boundaries (**see Figure 3.4**)

Box 3.2 Soybean exportation and nutrients (NPK) flows

Depletion of soils due to mining and industrial agricultural models is a key point of current ecological imbalances, with serious results for nutrient stability in the some of the world’s best soils. The case of soybean and soil export in Argentina is illustrative (Altieri and Pengue 2006). Argentina has historically amassed and exported large amounts of nutrients for worldwide consumption, being a large food and biomass supplier to the world and relying on the high productivity of its fertile soils.

A continuous process of soil’s nutrient depletion has been ongoing since 1961, as expressed by the last 55 years of nutrient extraction dynamics. The estimated nutrients harvested from 1961 to 2015 stood at 113 Tg of NPK (76 Tg N, 11 Tg P, 26 Tg K), equal to an annual national average extraction of 64 kg N ha-1, 9 kg P ha-1 and 22 kg K ha-1 (Díaz de Astarloa and Pengue 2016). This soil exhaustion represents a ‘hidden cost’ or environmental intangible (Pengue 2009), since the export of nutrients from soils as natural capital remains unaccounted for. This ecological trade-off needs to be reconciled in order to minimize environmental impacts, avoid soil degradation and sustain the ability of the landscape to produce food. Argentina is seen as the “barn of the world”, owing to its high quality soils, especially in the Pampas region, but it can also be portrayed as a main extractor of nutrients. The main consumers of these virtual soils are located in Asia (especially China), Europe and Africa (see **Figure 3.11**)

Figure 3.11 Nutrients exported in soybean products from Argentina (2007-2017) (Source: Diaz de Astarloa and Pengue 2016)

in design

3.3.4 Logistics and transportation costs in the food chain

Food travelled 50 per cent farther in the early 21st century to reach the UK and 25 per cent further to reach the USA compared to distances travelled in the 1980s (Halweil 2002). The increase in food transport distances and the reduction in maritime transport costs and logistical and port costs has not only negatively impacted the environment but also increased the risks related to food quality, biosafety, invasive species, and traceability.

Logistics refers to the movement (forward and reverse) and storage of goods (food, food-producing animals and other agricultural goods) and associated financial and information flows. Since logistics activities require extensive use of human and material resources that affect a national economy, developed countries like the UK and USA have devoted considerable attention to improving the technology and management of logistics activities and costs (Bosona 2013).

In developing countries, on the other hand, the available transport infrastructures are relatively poor and physical destruction of transported foodstuffs are common due to flooding, local and regional conflicts, and lack of appropriate storage facilities and maintenance. Inadequate logistics services are associated not only with food waste but also with food contamination and spread of disease at different stages of the food supply chain (Bosona 2013).

With respect to storage facilities, in many countries, especially poor countries, on-farm storage capacity is lacking. In addition the lack of equipment and infrastructure to transport the produce to processing plants or markets immediately after harvesting also contributes to food loss. In some cases, the available transport services may be interrupted due to damage on roads caused by flooding or armed conflicts leading to product loss due to spoilage, theft or total damage. For example, in Uganda, dairy farmers were forced to stop marketing their milk because of flooding in 2007 (Choudhary et al. 2011). In countries such as El Salvador or Ecuador, logistical and transportation costs rise as results of earthquakes. Inadequate logistics services are associated not only with food waste but also with food contamination and spread of disease at different stages of the food supply chain (Bosona 2013). Logistical risks in agriculture are broad and varied; this chapter section focuses on the major types.

Logistics-related food loss is high in low-income countries. Comparatively, food loss at the consumption level is higher in high-income countries. In Sub-Saharan Africa, around 8 per cent of cereal production, 15 per cent of dairy production, and more than 35 per cent of fruits and vegetable products are lost due to logistics-related problems (Gustavsson et al. 2011). Even in industrialized Asian countries (Japan, China and South Korea), around 15 per cent (142 million tons per year) of fruits and vegetables are lost due to logistics related problems. Punctures (due to inappropriate containers and packaging), impacts (due to bad roads and driving behaviour), compression (due to overfilling of containers and inappropriate loading), and vibration (due to rough roads and bad driving behaviour) as well as exposure to high or low temperature, moisture, chemical contaminants and insects are main causes of logistics-related damages to fruits and vegetable products.

According to information obtained from the FAO, global fish loss caused by spoilage is significant, totalling around 10-12 million tons per year (HLPE 2014). In Latin America, South and Southeast Asia, approximately 25 per cent of fish and seafood products are lost due to logistics-related problems, because high levels of deterioration occur during distribution of fresh fish and seafood (Gustavsson et al. 2011). Similarly, the logistics-related loss in dairy products is significant (more than 10 per cent) in developing countries. Inability to market milk products during rainy season, lack of properly refrigerated transportation, erratic power supply to milk processors and coolers are some of the causes of losses in dairy products (Gustavsson et al. 2011).

Logistics-related risks also occur in the transportation of food producing animals. Transport of livestock is known to be stressful and injurious, which leads to production loss and poor animal welfare. For example, in the USA, about 80,000 pigs die per year during the transportation process (Greger 2007). A case study in Ghana indicated that more than 16 per cent of expected income is lost due to occurrence of death and sickness or injuries of cattle during transport from farm to cattle market and abattoir (Frimpong et al. 2012). A similar case study in central Ethiopia (Bulitta et al. 2012) indicated that during cattle transport from farm to central market, over 45 per cent of animals were affected (either stolen, injured or killed).

3.3.5 Effects of socio-economic crises

The effects of volatile food prices along with financial and economic crises can impact the most vulnerable by lowering or disrupting real wages and impacting their major sources of income. High food prices threaten to reverse critical gains made towards reducing poverty and hunger (Weinberger et al. 2009). During the economic and financial crisis a decade ago (2008), FAO estimates that higher food prices meant that nearly 1 billion fell below the hunger threshold by the end of 2008 before improving slightly in 2010 to around 925 million (Thompson 2008).

Disasters destroy critical agricultural assets and infrastructure, and cause losses in the production of crops, livestock and fisheries. They can change agricultural trade flows, and cause losses in agricultural-dependent manufacturing sub-sectors such as textiles and food processing industries. Disasters can slow down economic growth in countries where the sector is important to the economy and where it makes a significant contribution to national Gross Domestic Product (GDP). Agriculture contributes as much as 30 per cent of national GDP in Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Ethiopia, Kenya, Mali, Mozambique, Nepal and Niger among others, as examples of countries where natural disasters have had massive impacts (FAO 2015b). Between 2003 and 2013, natural hazards and disasters in developing countries affected more than 1.9 billion people and caused over USD 494 billion in estimated damage (ibid.).

When disasters strike, they have a direct impact on the livelihoods and food security of millions of small farmers, pastoralists, fishers and forest-dependent communities in developing countries. Agriculture employs over 30 per cent of the labour force in countries such as Bolivia, Cambodia, Cameroon, Guatemala, India, Indonesia, Nicaragua, Niger, Philippines, Sri Lanka, and Viet Nam, and over 60 per cent of people in Burkina Faso, Ethiopia, Kenya, Madagascar, Mali, Tanzania, Uganda and Zambia.

In order to add an additional layer of analysis to the damage that disasters—including small-scale disasters—cause to crops and livestock, FAO used the DesInventar database, which reports damages to crops in hectares, and to livestock in units lost on the basis of 56 national databases. According to the data reported in DesInventar, 58 million hectares of crops were damaged, and 11 million livestock lost due to disasters occurring between 2003 and 2013. FAO used the same data, and the formula applied in the United Nations International Strategy for Disaster Reduction Global Assessment Report 2013 to calculate the monetary value of this physical damage, at approximately USD 11 billion. This figure is comparable with the results from post-disaster needs assessments, which covered medium- and large-scale events in 48 countries, indicating a total damage to crops and livestock of around USD 7 billion (FAO 2015b). Both DesInventar data and the post-disaster needs assessments analysis represent an underestimate of the overall damage caused by natural hazards and disasters to agriculture since they cover only 48 to 56 countries.

Over the past 30 years, the typology of crises has gradually evolved from catastrophic, short-term, acute and highly visible events to structural, long-term and protracted situations resulting from a combination of multiple contributing factors, especially natural disasters and conflicts. Climate change, financial and price crises are increasingly common exacerbating factors. In other words, protracted crises have become the new norm, while acute short-term crises are now the exception. Indeed, more crises are considered protracted today than in the past (FAO 2015b; HLEF 2012). In this respect, it should be noted that changes related to climate change (such increase in temperature, shift in precipitation) are slow, and in many places they have not yet been perceived as a crisis, yet they may already affect availability and accessibility of food.

From a food security and nutrition perspective, in 1990, only 12 countries in Africa were facing food crises, of which only four were in protracted crisis. Just 20 years later, 24 countries were facing food crises, with 19 of these having been in crisis for eight or more of the previous 10 years (FAO 2015b). In 2016 the number of chronically undernourished people in the world is estimated to have increased to 815 million, up from 777 million in 2015 although still down from about 900 million in 2000 (FAO 2017a). Moreover, the growing imperative of dealing with the long-term contexts of these emergencies is becoming evident. For instance, the Bosphorus Compact reported that global humanitarian appeals between 2004 and 2013 increased by 446 per cent overall – rising from US$3 billion to US$16.4 billion (FAO 2015b). Similarly, the number of displaced people at the end of 2013 was 51.2 million, more than at any point since the end of World War II (FAO 2015b). The average length of displacement in major refugee situations is now 20 years. Over the past three decades, humanitarian crises have grown in complexity and length. Nine out of ten humanitarian appeals continue for more than three years, with 78 per cent of the spending by the Organisation for Economic Cooperation and Development (OECD)'s Assistance Committee donations allocated to protracted emergencies. Human-induced conflicts are increasingly the main underlying cause for food crises, often related to or being amplified by natural disasters (FAO 2015b).

The complex relation between conflict and food security and nutrition is yet to be fully explored, but the capacity for conflict to accelerate food insecurity and famine is evident in many recent events. Food insecurity can be a direct result of violent conflict and political instability as well as an exacerbating factor. On the one hand, food insecurity is a factor that can trigger and/or deepen conflict, often due to underlying economic and structural factors. For instance, sudden and unforeseen food price rises, or the reduction or removal of subsidies on basic foodstuffs, can be a catalyst for civil and political unrest, as in the social upheaval and political violence of the Arab Spring in 2011 when governments in the Near East reduced subsidies for bread (FAO 2015b). Natural disasters, drought and famine can also contribute to political unrest and violent conflict, as evidenced by the Sahel and West Africa region. Food insecurity can exacerbate political instability and violent conflict when specific groups are economically marginalized, services are distributed inequitably or where there is competition over scarce natural resources needed for food security.

Periodic conflicts between farmers and herders in the semi-arid Sahel and East Africa regions illustrate this.

In the worst of cases, widespread famine may result. All situations of extreme food insecurity and famine in the Horn of Africa since the 1980s have been characterized by conflict in some form, transforming food security crises into devastating famines. Globally, between 2004 and 2009, around 55,000 people lost their lives each year as a direct result of conflict or terrorism. In contrast, famine caused by conflict and drought resulted in the deaths of more than 250,000 people in Somalia alone between 2010 and 2012 (FAO 2015b).

3.3.6 Poverty and food security in relation to multiple forms of crises

Economic crises - including those that are generated by climate, weather and land/water resource degradation leading to the loss of crops, displacement and migration - generally produce massive disruption to food systems, both at the supply and demand end. The changing agricultural scenario caused by these crises often results in a vicious cycle involving the inability of farmers to make meaningful investments or get adequate returns from their resources. This cycle, which starts with broader economic crises, has its initial impacts at the farm level, and can then spread in many places to the larger local community and to regional levels.

Economic crisis and natural disasters make the poor even poorer: The decline in GDP due to large-scale disasters, which increase the depth and extent of poverty especially in affected developing countries, is often accompanied with loss of employment and income opportunities in the affected sectors. The need to replace damaged infrastructure also means that governments have to divert resources from long-term development objectives, compromising efforts to reduce poverty and food security.

When emergencies occur, households often resort to selling their assets, such as livestock and other holdings, to meet their emergency food needs. In extreme circumstances, people migrate in search of relief and employment. Poor households that incur injury and disability are hit harder, affecting their ability to work. The disruption of livelihood systems, with severe and repeated crop failure, results in further pauperization of households and communities.

The developing world has made substantial progress in reducing hunger since 2000. The 2016 Global Hunger Index (GHI) shows that the level of hunger in developing countries as a group has fallen by 29 per cent (IFPRI 2016). Yet this progress has been uneven, and great disparities in hunger continue to exist at the regional, national, and subnational levels. To achieve Sustainable Development Goal 2 (SDG2) of getting to Zero Hunger while leaving no one behind, it is essential to identify the regions, countries, and populations that are most vulnerable to hunger and undernutrition so progress can be accelerated there (IFPRI 2016).

About 795 million people are undernourished globally, down 167 million over the last decade, and 216 million less than in 1990–92. The decline is more pronounced in developing regions, despite significant population growth. In recent years, progress has been hindered by slower and less inclusive economic growth as well as political instability in some developing regions, such as Central Africa and western Asia (FAO 2015a). In Africa the absolute number of hungry people has trended upward since 1996, even if the prevalence of undernourishment has gone down.

Economic growth and hunger: There are multiple complexities involved in the relationship between economic growth and hunger involving many political and governance aspects, although in general, undernourishment declines with increased growth (see **Figure 3.12**).

Economic growth and prevalence of undernourishment: Stunting and malnutrition of children has a very negative effect on the economic prospects of a population. While the overall trends are consistent, there are undercurrents and drivers in such trends that impact poverty and hunger. Economic growth increases household incomes through higher wages, increased employment opportunities, or both, due to stronger demand for labour. In a growing economy, more household members are able to find work and earn incomes. This is essential for improving food security and nutrition and contributes to a virtuous circle as better nutrition strengthens human capacities and productivity, thus leading to better economic performance. However, the question here is whether or not those people who are living in extreme poverty and are most affected by hunger will be given the opportunity to participate in the benefits of growth and, if they are, whether they will be able to take advantage of it. Governmental and political concerns also directly impact whether people are able to engage in economic activities.

In several cases, the positive effects of economic growth on food security and nutrition are related to greater participation of women in the labour force. In Brazil, for example, labour force participation of women rose from 45 per cent in 1990–94 to 60 per cent in 2013. In Costa Rica, the proportion of women workers increased by 23 per cent between 2000 and 2008. Spending by women typically involves more household investments in food and nutrition, but also in health, sanitation and education, compared to the case when men control resources (FAO 2015a). As documented by Smith and Haddad (2015) sanitation and female education are the largest factors related to reductions in child malnutrition, before levels of calorie production.

Figure 3.12 Economic growth and prevalence of undernourishment (Source: FAO 2015a)

in design

3.3.7 Migration

According to the UN, "Migration is the movement of people, either within a country or across international borders. It includes all kinds of movements, irrespective of the drivers, duration and voluntary/involuntary nature. It encompasses economic migrants, distress migrants, internally displaced persons (IDPs,) refugees and asylum seekers, returnees and people moving for other purposes, including for education and family reunification" (FAO 2016a).

In 2015, there were 244 million international migrants, representing an increase of 40 per cent since 2000. They included 150 million migrant workers. About one-third of all international migrants are aged 15–34. Women account for almost half of all international migrants. A large share of migrants originates from rural areas. Around 40 per cent of international remittances are sent to rural areas, reflecting the rural origins of a large share of migrants. International remittances are estimated at three times the size of official development assistance. Internal migration is an even larger phenomenon, with 763 million internal migrants according to 2013 estimates. Internal and international migrations are often interconnected. In 2015, 65.3 million people around the world were forcibly displaced by conflict and persecution, including over 21 million refugees, 3 million asylum-seekers and over 40 million internally displaced persons (IDPs). A quarter of global refugees reside in only three countries (Turkey, Pakistan and Lebanon) (FAO 2016a).

The picture of dietary change in the face of such high levels of internal and international migration is complex, depending on a variety of factors related to country of origin, urban/rural residence, socio-economic and cultural factors and situations in host countries. The main dietary trends after migration are a substantial increase in energy and fat intake, a reduction in carbohydrates and a switch from whole grains and pulses to more refined sources of carbohydrates, resulting in a low intake of fibre. The data also indicate an increase in intake of meat and dairy foods. Some groups have also reduced their vegetable intake (Holmboe-Ottesen and Wandel 2012).

3.3.8 Biodiversity

Agriculture and its impacts on biodiversity are one of the major challenges to global sustainability. Food systems and the world's biodiversity interact in multiple dimensions. Agricultural biodiversity – from seeds to soil organisms to pollinators – underpin agricultural production and have an inestimable utilitarian value to human societies. In their own right, wild species of animals, plants and other organisms have intrinsic value. Yet current food systems – certainly modern and some mixed systems – pose the greatest threat to terrestrial wild species on Earth. It is crucial to consider not only the impacts of farming practices for on-farm biodiversity, but for off-farm biodiversity as well (through pollution, agricultural expansion and deforestation, fires, etc.), and in this respect different food and farming systems and their associated trade patterns have varied impacts on biodiversity Similar to the discussion of "virtual flows" of land and soil, virtual flows of biodiversity occur through such trade and associated supply chains. Developing country such as Indonesia, Madagascar and Papua New Guinea are losing biodiversity at high rates while developed countries such as the US, EU and Japan import large quantities of the commodities implicated in major biodiversity losses (Lenzen et al. 2012).

3.3.9 Food production, food scarcities, food access and governance in a complex world

The world food crisis (2007-2008), stemming from spiralling perceptions and concerns over of high oil prices, climate change, financial and banks meltdowns, and the consequent political reactions, has raised awareness about the lack of appropriate food system governance and pointing to the need for profound changes in the food system. On the supply side, the growing competition for land, energy and water leads to resource depletion, under current conventional practices. The paradigm of "structural transformation" that shaped economic thought and development theory for many decades envisioned a future of agriculture with industrial styles of production, with fewer farmers feeding growing urban populations (Herrendorf et al. 2014). Many questions remain on this envisioned future, amongst which are the realities of large rural populations likely to persist in India and sub Saharan Africa (Dorin 2017).

On the demand side, the world's population continues to increase, albeit at diminishing rates. Urbanisation of the world already transformed the ways food is produced, purchased and marketed (UNEP 2014). In many countries with growing economies, people would like to eat a richer diet that demands more resources to produce, yet there is at present no governance system that can help make the larger societal decisions that could guide diet changes while not incurring further environmental, social and health costs. The dearth of laws and legal institutions that could mitigate the dangers of inequality and promote greater fairness in food governance (Kennedy and Liljeblad 2016) is a major roadblock to ensuring rational, informed decision making and governance over food systems on many levels.

3.4 PATHWAYS TO SUSTAINABILITY FOR AGRICULTURE AND FOOD SYSTEMS

In this chapter so far, global external forces and economic pressures on the food system have been reviewed, and the resulting invisible flows of resources as a result of these forces and pressures were examined. Further evidence of a system that is cracking under pressure can be seen in the linkages between conflict, famine, migration, poverty and malnutrition, and the failures of governance. In this section, we intend to look for the pathways to reverse these trends. In important respects, the findings outlined above also hold the keys to understanding how we can pursue greater sustainability in the food system and more stable and resilient production of agricultural products.

3.4.1 The interdependence of nature and agriculture

Agricultural systems are part of the geological, biological and social processes that occur in the biosphere, so their evaluation must consider these interdependencies. Humanity has been farming for at least 10,000 years. For most of that time, agriculture has been small-scale, labour-intensive, and dependent on making use of, and modifying, natural processes to support food production. In understanding TEEBAgriFood, we recognize that there has existed a rich heritage and knowledge base in using nature to underpin agriculture. As detailed in earlier sections of this chapter, however, the last half century or more has witnessed a rapid revolution in the technology of agricultural production, particularly in the developed world, that has allowed the widespread adoption of industrial-scale farming techniques. By its very nature, modern agriculture to a large extent involves breaking such dependencies, managing land in ways that conflict with the conservation of biodiversity and the healthy functioning of ecosystems. Pathways to sustainability, going forward, must entail recognizing and strengthening those forms of agricultural production that explicitly enhance those ecosystem services and build the natural capital that underpin food systems, creating regenerative forms of agriculture and food that generate multiple positive externalities. In each of the subsections below, we first delineate the nature of these interdependencies and how they have been disregarded by modern conventional agriculture, before exploring how they may be restored.

Biogeochemical flows: Biogeochemical flows, coupled with changes in terrestrial ecosystems, are one of the key aspects of the global system models used within the United Nations Framework Convention on Climate Change to understand interactions between human activity and the world's climate systems (Prinn 2013).

While the use of nitrogen in agriculture is estimated to have increased 8-fold over the period of 1960 to 2000, many studies also reveal extremely low N use efficiency (Fixen and West 2002; Liu et al. 2010), resulting in the global nitrogen flows noted in earlier sections. However, there are many ecosystem-based measures that can reduce this "leakiness". Many begin with finding other sources of nitrogen other than the extremely labile nitrogen in conventional fertilizers, drawing on the ecological process of nitrogen fixation through crop rotation and cover crops. These, along with measures to facilitate the ecosystem service of nutrient cycling through applications of compost and organic manure, enhance the capacity of soils to hold and supply plant nutrients, and improve nitrogen capture by crops.

Such practices are of great importance in tropical areas where traditionally, farmers have fallowed portions of their land to restore soil fertility through natural processes. But farming plots have diminished in size, customary fallow periods have been reduced to essentially zero in many localities. Without other measures to sustain soil healthy and fertility, organic matter of soils is being reduced and crop yields inevitably follow. Thus, replacing fallowing with other soil fertility ecosystem services is critical (Bunch 2016).

Measures on a landscape level can recapture lost nitrogen from fields by applying watershed-level strategies, such as encouraging diversity in agricultural landscapes, including hedgerows, vegetated strips and riparian habitat (Robertson and Vitousek 2009). Analyses of whole food systems have shown considerable opportunities to reduce nitrogen contamination of ecosystems while sustaining food productivity (Smil 2002), including modifying trade patterns to become more localized (Billen et al. 2014).

Equally, the current agricultural use of phosphorus in fertilizers have profoundly altered global phosphorous cycles, such that it is thought to be accelerated two to three time over background rates (Smil 2002), leading to widespread eutrophication of the world's freshwater and estuarine systems (Bennet et al. 2001; Conley et al. 2002) and negative impacts on biodiversity (Wassen et al. 2005). Access to a limited resource such as phosphorus is as much an economic issue as a natural resource issue, in particular for smallholder farmers in different parts of the world. Its sustainable and equitable use needs to be addressed in an appropriate transdisciplinary manner (Scholz et al. 2013). As with nitrogen, the focus of mitigation is first to reduce introducing additional phosphorous to systems through building soil health. A second key approach is to increase the use of recycled phosphorus, to the extent possible, from manure, human excreta and food residues (Elser and Bennet 2011). In addition, watershed-level measures to establish and maintain riparian buffers and restore wetlands are being called upon to reduce phosphorous loss to aquatic systems (Cordell and White 2013).

All of these measures seek to draw biogeochemical flows into tighter cohesion, reducing inputs and deleterious outflows, while building the natural capital and capacity of agricultural ecosystems to generate and retain its sources of growth and fertility.

Control of pests and diseases: Pest and diseases of crops and livestock have consistently been some of the most challenging problems facing farmers throughout history. It is increasingly recognized that the approach that industrialized, modern agriculture has taken to controlling pests – through application of pesticides in sprays or seed treatments generates far more problems than it solves. Global pesticide use has grown over the past 20 years to 3.5 billion kg/year, amounting to a global market worth $45 billion (Pretty and Bharucha 2015). Pesticide and herbicide resistance continues to grow even as the toxicity of pesticides increases (Cresswell 2016). In a recent review of the global impact of agricultural insecticides on freshwater, it was reported that the concentration of 50 per cent of the insecticides detected in freshwater exceeded regulatory thresholds for environmental and human health (Stehle and Schulz 2015). Losses to pests and disease are estimated at 20-40 per cent of global crop yields (FAO 2015c), indicating this is not a battle that is being won by conventional crop protection. Secondary pest outbreaks and growing resistance on the part of pests - both plant and animal – are key problems for modern agriculture (Hill et al. 2017). Reports of insect pest problems and crop losses indicate increasing trends of pest outbreaks for a number of commodity crops such as cotton, sugarcane and tobacco (Dhaliwal et al. 2010). Estimates of the externalities of pesticides are from $4–$19 per kg of active ingredient applied, suggesting that efforts to reduce pesticides will benefit a wide group of stakeholders from farmers to consumers and those concerned with health (Pretty and Bharucha 2015).

Thus the science of pest and disease control is increasingly returning to its original roots: recognizing first that not all insects or microorganisms are pest or disease agents, and that there is almost always as subcritical level of both herbivores and pathogens in agroecosystems. Ecological approaches work to restore those balances when they become critical, through a host of careful monitoring, use of cultural techniques and on-farm diversity, choice of appropriate varieties and introduction of natural enemies. For example, and as profiled in the rice case study in Chapter 8, rice production systems managed with ecological approaches are capable of generating multiple ecosystem services, including sustaining natural pest control and inherent fertility. This approach is undermined by the use of agrochemicals, leading to severe pest outbreaks (Thoburn 2015; Settle et al. 1996). Building natural capital in agroecosystems is an investment over time, to create an environment favourable to natural enemies and other beneficial insects.

The UN Convention on Biological Diversity (CBD), with a focus at its 13th Conference of Parties on mainstreaming biodiversity into the agriculture, fisheries and forestry sectors, has presented case studies (together with FAO) of the contribution of biodiversity-mediated ecosystem services such as pest and disease control to agricultural production in East Africa and the Pacific Region (FAO and CBD 2016a; 2016b).

Pollination: Pollination as a factor in food production and security has been little understood and appreciated by conventional agronomy, in part because it has been provided by nature at no explicit cost to human communities. However, over the last two decades, there is a deeper understanding that the pollination contributes to the yields of at 35 per cent of all crops (Klein et al. 2007), particularly those that provide critical vitamins and other nutrients (Smith et al. 2015). At the same time, as farm fields have become larger, and the use of agricultural chemicals that impact beneficial insects such as pollinators along with plant pests has increased, pollination services are showing declining trends. The domesticated honeybee (and its several Asian relatives) have been utilized to provide managed pollination systems, but for many crops, honeybees are suboptimal pollinators compared to wild species. Thus, the process of securing effective pollinators to "service" large agricultural fields is proving difficult to engineer, and there is a renewed interest in helping nature provide pollination services. A recent global meta-analysis provides insight into how this ecosystem service can best be secured (Garibaldi et al. 2016). Smallholder farmers, cultivating fields of less than two hectares, can effectively increase yield gaps by a median of 24 per cent by promoting greater visitation of pollinators to their crops; their already high levels of diversity support populations of pollinators that can be enhanced by relatively simple measures. For larger, more intensive forms of cultivation, similar benefits can be found, but only by very focused measures to increase the diversity and richness of pollinators (of which, reducing the use pesticides is an important one).

For this ecosystem service as for others, there can be synchronous benefits for biodiversity and for agriculture (Gemmill-Herren 2016; IPBES 2016). The CBD has recognized the contribution of pollination to human welfare, through the establishment (and recent renewal) of the International Initiative on the Conservation and Sustainable Use of Pollinators[3]. The first thematic assessment carried out by the IPBES was on pollinators, pollination and food production, thoroughly documenting the role and value of both wild and managed pollinators to global food production (IPBES 2016).

Freshwater use: There remains uncertainty over the extent to which freshwater planetary boundaries are being exceeded by agriculture's use of water (Campbell et al. 2017). In certain regions conventional water impoundment, groundwater pumping and irrigation schemes for agriculture around the world have had serious impacts on water quality and quantity for communities and for nature. If watershed services (understood as water purification, ground water and surface flow regulation, erosion control, and streambank stabilization) are appreciated as being the context within which water is locally provisioned, ways of managing freshwater use can be seen as integral to ecological approaches in agriculture.

The fundamental role of freshwater in support of the environment, society and the economy, and its interactions with farming activities is recognized directly by at least two Sustainable Development Goals (2 and 14) and UNEP's Freshwater Strategy 2017-2021 (UNEP 2017); in fact, freshwater is implicated in all sustainable development goals.

Seeds and genetic diversity: The diversity of species contributing to agricultural production has seen a dramatic narrowing over recent decades, as a few major energy-dense cereals (maize, wheat and rice) and major oil crops have come to dominate both production and global diets. (Khoury et al. 2014), accompanied by declines in consumption of pulses (Akibode and Meredia 2011) and underutilized crops (Padulosi et al. 2002). Food supplies worldwide have become more homogenous and composed of processed food products, to the detriment of local, often better adapted and more nutritious food crops such as other cereals, root crops and diverse beans (Khoury et al. 2014). Yet genetic diversity, as manifested in seeds and livestock breeds, is greatly appreciated as an ecosystem service that is essential to sustainable agriculture (Haijer et al. 2008). Even within any of the major crops, the attributes of diverse seeds remain of great value, contributing to multiple ecosystem services and resilience. The example of rice featured in a TEEBAgriFood feeder study (Bogdanski et al. 2017), noted that with its long history of cultivation and selection under diverse environments, rice has acquired a wide adaptability, enabling it to grow in a range of environments, from deep water to swamps, irrigated and wetland conditions, as well as on dry hill slopes. The quality preferences of rice consumers, over millennia, have resulted in a wide diversity of varieties

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[3] See, for example, document CBD/SBSTTA 22/10.

specific to different localities. There are estimated to be around 140,000 different genotypes among thousands of different rice varieties, some of which have been around for centuries while others are new hybrids bred to increase rice yields or reduce the susceptibility to rice pests. While the governance over genetic resources remains a contested space, many believe that legal frameworks should support a pluralistic variety of seed supply and encourage exchange with farmers served by a number of institutions, including – but not limited to – those in the private sector and intergovernmental bodies, including the CBD, the Commission on Genetic Resources for Food and Agriculture, and the International Treaty for Plant Genetic Resources. Many other actors focus on civil-society mechanisms to ensure resilient and diverse seed systems. Such systems have values in many dimensions, beyond economics, including cultural diversity, culinary traditions, health and wellness, and resilience (Global Alliance for the Future of Food 2018).

Cultural diversity: Ecosystem services are not purely bio-physical in nature. Cultural diversity and traditional and local knowledge should also be respected as an ecosystem service that merits greater appreciation. Farmers' knowledge and understanding of management of local natural resources and knowledge of local cultural and social systems are a key foundation for building resilient eco-agri-food systems. The value of the context-specific and continuously adapted knowledge of farmers to find solutions for complex and dynamic ecological and human systems is inestimable. Increasingly, it is being recognized that co-creating knowledge between farming communities and scientists, and the many mediating organizations in between, including farmer organizations, non-governmental organizations, governmental extension agencies and community-based organizations can lead to designing adaptive food systems that effectively address food and nutrition security (ILEIA 2016).

Mechanisms to highlight cultural diversity, local traditions and farmer knowledge have been found, for example, in the recognition of agricultural heritage systems. The existence of numerous globally important agricultural heritage systems (Koohafkan and Altieri 2011) around the world testify to the inventiveness and ingenuity of people in their use and management of finite resources, biodiversity and ecosystem dynamics, and ingenious use of physical attributes of the landscape, codified in traditional but evolving knowledge, practices and technologies. The values of heritage systems reside in the fact that they offer outstanding aesthetic beauty, are key to the maintenance of globally significant agricultural biodiversity, and include resilient ecosystems that harbour valuable cultural inheritance, and also have sustainably provisioned multiple goods and services, food and livelihood security for millions of poor and small farmers, local community members and indigenous peoples.

A number of international processes are calling for the development of indicators that reflect the value of the ecosystem services and processes as described here, contributing to agriculture and sustainable development. Among these are the 2030 Agenda for Sustainable Development and the SDGs, the UN Framework Convention on Climate Change, the UN Convention on Biodiversity and the Aichi biodiversity targets and the UN's Global Strategy to Improve Agricultural and Rural Statistics, including the System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries (SEEA AFF) (FAO 2018). To take just one of these, the TEEB secretariat has mapped, as an example, the value generation from ecosystem services in Asian rice production systems to virtually all of the Sustainable Development Goals (see **Figure 3.13**).

Figure 3.13 Mapping of value generation in smallholder Asian rice production systems to the Sustainable Development Goals (Source: authors)

in design

3.4.2 Ecological management across landscapes

Farms are inherently embedded in natural and human systems. To apply ecological approaches, there is a need to work across and within landscapes, communities and territories. Certainly, managing freshwater resources occurs at a landscape or territorial scale, as does building appreciation for cultural diversity. Biodiversity conservation efforts are also best coordinated at these larger scales. Measures to use biodiversity to filter waterways and retain nutrients require landscape interventions. Farmer exchanges of seeds and other genetic resources occur within and between communities. Ecosystem services such as pollination and natural pest control stand to benefit tremendously from temporal, spatial, and genetic diversity resulting from farm-to-farm variations in cropping systems.

FAO and other actors have articulated landscape approaches to sustainable agriculture. (FAO 2017c; Tscharntke et al. 2005). Such approaches are designed to deal, in an integrated and multidisciplinary manner, with the multi-functional roles of production landscapes, bringing in environmental and social considerations to address underlying causes of degradation and food insecurity. Human activities and institutions are viewed as integral to agricultural systems, and multi-stakeholder involvement is often central to resolving management issues. Some examples of landscape approaches to sustainable agriculture include forest restoration and sustainable forest management to support watershed services for farmers as well as forest dwellers, and integration of fishery practices in irrigation and other water systems. Effectively and equitably integrating the benefits of multiple ecosystem services in land management and planning demands levels of ecological literacy, understanding of socio-economic conditions, and local governance systems at a landscape scale rather than at a local farm scale (FAO 2017c).

3.4.3 Environmental implications of changing diets: options and alternatives

As noted previously, broad patterns in diets are changing globally in fairly consistent ways, linked to increases in income and urbanization over the last half-century. Rising demands – in the sense of quantities food brought into a household - can be seen for meat, "empty calories" derived from refined sugars and fats, and total calories per person (Tilman and Clark 2014). Asian diets are in striking transition, led by China because of urban migration, a growing middle-class and rising incomes (see **Figure 3.14**). This global dietary transition- and its future trajectories- is one of the greatest challenges facing the world. While the impacts of changing diets on human health and nutrition are addressed in more depth in Chapter 4, in this section we present some of the current understanding of different, and changing, diets on the environment.

Greenhouse gas emissions from agriculture are highly dependent on the composition of diets. Tilman and Clark (2014) calculated annual per capita GHG emissions from food production, using the 2009 global average diet as a baseline and comparing this to an estimated global-average income-dependent diet projected for 2050, and to Mediterranean, pescetarian and vegetarian diets in 2050 (see **Figure 3.15**). Global-average per capita dietary GHG emissions from crop and livestock production would increase 32 per cent from 2009 to 2050 if global diets simply continued current trends, responding to the anticipated increases in income around the globe. If adopted globally, the three alternative diets on the other hand, would reduce emissions from food production substantially below those of the projected 2050 income-dependent diet with per capita reductions. These estimations also suggest that shifts in global diets towards more plant-based foods could substantially decrease future agricultural land demand and clearing. Tilman and Clark (2014) note, however, that reducing greenhouse gas emissions does not necessarily contribute to healthier diets; processed foods high in sugar, fats or carbohydrates can have low GHG emissions. Thus, as they note, solutions to the "diet-environment-health" trilemma should aim for healthier diets with low GHG emissions, rather than singularly seeking to minimize GHG emissions alone.

Regional differences in food production systems are striking, particularly between regions that primarily grow crops for direct human consumption versus those that produce crops for other uses such as animal feed or biofuels. Only around 40 per cent of North America and European croplands grow crops for direct human consumption, while the percentage of cropland so allocated in Africa and Asia is over 80 per cent (Foley et al. 2011). In addressing strategies to "feed the world", this massive allocation of fertile, productive land in North America and Europe to animal-based agriculture and of extensive pastures in tropical Latin America is increasingly called into question. As Foley et al. (2011) note, meat and dairy production can either add to or subtract from the world's food supply. Using highly productive land for animal feeds and biofuel reduces the world's potential food supply, while grazing of livestock on pastures that otherwise are unsuitable for food production, and mixed crop-livestock systems can add both calories and protein to levels of food production, while generating environmental, economic and food security benefits.

Figure 3.14 Per capita consumption of meat in selected countries or regions (Source: Wirsenius *et al.* 2010)

in design

As in any scenario, there are nonetheless important trade-offs to consider: the more unproductive grazing lands are often valuable for wild species of animals and plants, so utilizing them for livestock incurs large costs to biodiversity for minimal benefit in terms of food produced. It has been pointed out that "rewilding" (or restoring to its natural state) the less productive 50 per cent of grazed lands in US would have great benefits for biodiversity yet reduce current beef production by only 2 per cent (Eshel et al. 2018). Moreover, scenarios involving more sustainable systems of beef production inevitably hinge on reducing the quantities of meat and dairy production. With large reductions in animal product production, while maintaining some mixed and pastoral systems, environmental benefits can be achieved, but the greatest benefits will come from scaling back the more harmful forms of livestock production, particularly extensive pastures in wet and dry tropical forest regions of Latin America.

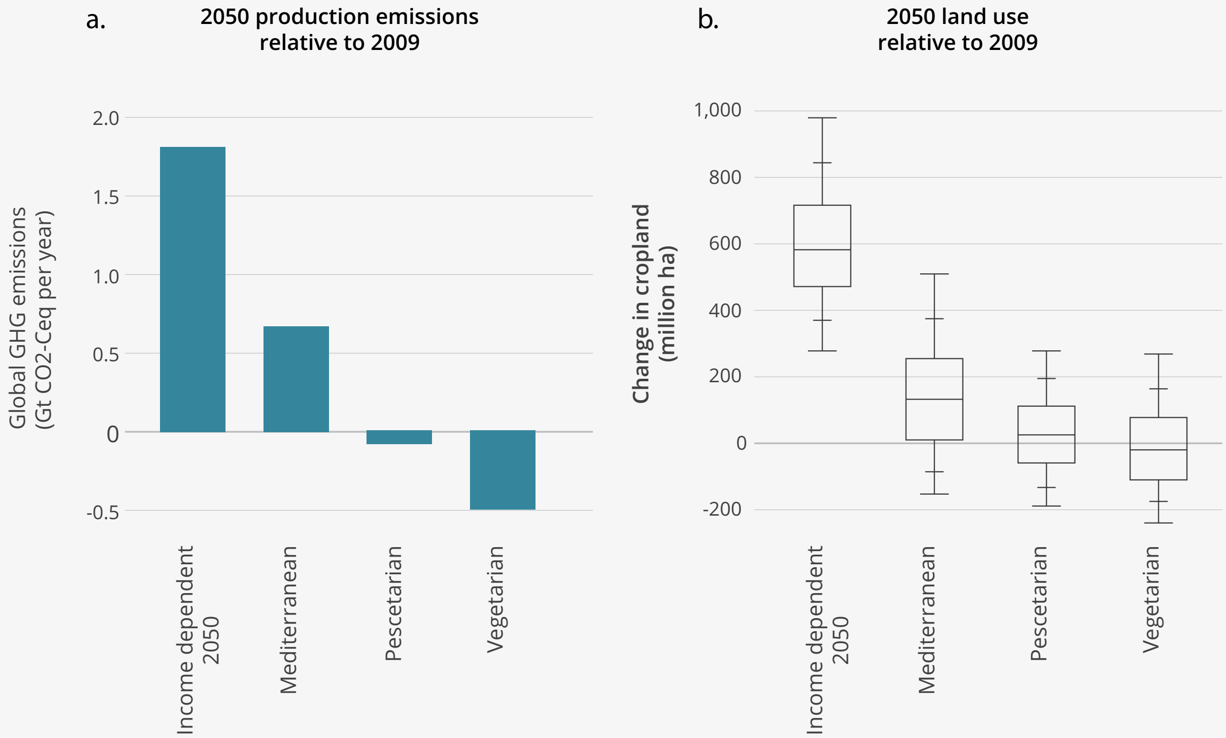
3.4.4 Ecological management at system levels

Transitions to sustainable farming systems take place in steps. The diversity of such steps, and a useful typology of resulting farming systems have been recently presented in Therond et al. (2017). They suggest a gradient, from the chemical input-based systems of industrial agriculture, based on simplified crop sequences and systematic use of chemical inputs, to biological input-based farming systems, based on still fairly simplified crop sequences but with "environmentally-friendly" inputs and managements such as organically certified fertilizers and precision agriculture, to biodiversity based farming systems, applying ecosystem services as described above, in a whole-system design. It is also recognized, within this gradient, that socio-economic contexts of the food system are also important, a topic we explore below.

TEEBAgriFood posits that pathways to sustainable food systems must look at dependencies and interactions along the entire food chain. Indeed, while place-based ecological management of natural resources to underpin sustainable production is of key importance, analysis across the food chain is of at least the same if not greater importance in order to understand where cost shifts or benefits can be accrued through changes in governance and management. Three examples illustrate the importance of a food chain/holistic system assessment:

Food waste: while using ecosystem service approaches as outlined above (for nutrients, freshwater use, etc.) can substantively contribute to creating regenerative agricultural ecosystems, addressing food waste in storage or after-market waste could have an equally substantive contribution. If the estimated 30 per cent of food that is lost to waste were not lost, less would need to be produced in the first place, with less use of resources (Gustavsson et al. 2011)

Figure 3.15 Effect of diets on GHG emissions and cropland (Source: Tilman and Clark 2014)



An overarching question that should frame holistic analyses is what are we producing, for whom, and why? The consumption of freshwater in connection with livestock production, for example, is a case in point: the amount of water needed to produce food depends on what is being cultivated and the production method. With a growing human population and a shift in dietary preferences toward more meat and dairy, it is always assumed that ever more water will be required. The growth in livestock production, in particular, increases water consumption owing to the extra demand for water to grow crops used to feed livestock. Alternatives, that urgently need consideration, are to work to revise diets for a healthier, and smaller level of meat consumption, and a focus on meat production with less wholesale reliance on feed grains, often shipped from long distances (see case study 3 on meat production in Chapter 8). While livestock production provides much needed protein in critical food insecure regions, its overproduction in many other region has strong impacts on environmental and human health, without contributing to food security.

In a related vein, the 'virtual flows' – of water, nutrients, soil, biomass – as described above, too often are invisible flows, not counted in local environmental assessments. An accurate understanding of food systems should recognise such flows, and their somewhat hidden environmental footprint. A diet based, for example, on less sugar, starch and fat but greater consumption of fish caught by the industrial fishing vessels in waters off West Africa cannot claim high marks for sustainability if the entire "ecosystem service burden" is considered (Pascual et al. 2017b).

3.4.5 Holistic assessment of food chains

The contemporary scientific analysis of agriculture is fragmentary, focusing on economic interpretations of agriculture and trade, while disregarding broader relationships to the local and global environment, and social organizations, as well as visible and invisible flows of material and energy. Many aspects are "missing in the frame", which need to be addressed in holistic assessments that TEEBAgriFood promotes.

Missing in the frame: social and environmental aspects: The dominant paradigm of neoclassical economics looks at man as a rational economic entity who, based on the information available, makes rational decisions, maximizes his own benefit and interest, and minimises the risk while achieving the specific goals- usually narrow economic ones. Under this general context, a monetary approach neglects other values. This conventional frame of economics does not include social, cultural and behaviour patterns, or the needs of non-human species (biodiversity). Measures which many capture these elements of overall systemic performance more fully in rural areas could include employability, environmental health, social welfare and well-being, resilience, self-organization, and autonomy.

Missing in the frame: materials and energy in food-value chains: In terms of energy, agricultural systems imply interactions between physical and economical entities. At each stage, it is the added energy, materials and human labour that cause accumulations or losses in the transactions carried out. By introducing an energy analysis into a monetary analysis (Ulgiati et al. 1995),

may be more evident to see where the benefits of various trade patterns accrue. In an agricultural economy that depends heavily on fossil fuels, both for agricultural inputs, mechanization, storage and transport, the consumption of energy along the food value chain along with associated greenhouse gas emissions, are important attributes impacting sustainability (Siche et al. 2008). Material and energy flows and their balances are key points to be considered in a sustainable agricultural and food systems approach; these are generally overlooked in any partial energy analysis. Looking at the complete balance of energy in systems could help to reach to better decisions facing a very complex food system (Fan et al. 2018).

3.4.6 3.4.6. Reaping the benefits of food value chains and local trade

In the earlier sections of this chapter so far, the external forces and economic pressures globally have been reviewed, and the resulting invisible flows of resources as a result of these forces and pressures were examined. Further evidence of a global system that is cracking under pressure can be seen in the linkages between conflict, famine, migration, poverty and malnutrition. On local levels, however, there may be more openness and incentives for virtuous cycles that benefit local communities and address their needs for environmental and social sustainability.

Benefits can include culturally appropriate food supplies and closer producer-consumer links with fewer impacts on the environment, while costs of supporting local over global food chains might include a relatively smaller variety of supplied products present in markets and mainly found only on a seasonal basis. It is presumed that through promoting local over global trade, there will be lower negative trade-offs in the economic, social and environmental realms, and reduction of carbon emissions in transport, adding on to sustainability. This does not always hold true, in that, in general, the impacts of production systems are more important in most cases than those of transport (see, for example, Weber and Matthews 2008). It should also be recognized that local has different meanings in different places. Geographical radiuses might vary depending on the area to be supported by local food systems through local trade. Increasingly it is recognized that local food production may provide one means of addressing food crises and food insecurity while reducing the negative social and environmental impacts of food systems. Under economic crises, in developed as well in developed countries, local food production in peri-urban and urban areas is a contribution to helping local communities overcome negative impacts on food systems. Economic crisis, particularly in a context of inflation, tends to worsen market food access for the most vulnerable sectors of the population by exacerbating two main factors: the price of food and the income level.

A number of illustrations showcasing the development of greater capacity for "self-production" or more localized production as lever for community resilience are relevant here. In recent history, Argentina has suffered at least three inflationary crises (1975, 1989-90 and 2001-02). During the second inflationary crisis, a proposal to diversify and increase the dietary quality of the vulnerable sectors emerged. This initiative, named ProHuerta, sought direct food access by self-production of agroecological gardens, and it was initially conceived as a transitional food security project to face the existing social emergency. Regular assessments permitted the documentation of the dietary, social and environmental impacts. In nutritional terms, produce from family orchards provided not less than 72 per cent of globally recommended dietary consumption, and as much as 75 per cent and 37 per cent of vitamin A and C needs, respectively (Britos 2000). In 2016, after twenty-six years of implementation, more than 2.8 million people had been integrated into the Program, involving more than 560,000 family orchards, including 12,000 educational and communitarian orchards. Similarly, under complex socioeconomic and environmental conditions in Haiti, self-production of food showed success in fighting food insecurity, using the methodology and technical approaches of ProHuerta as applied in partnership with several governments and international aid institutions (Canada, Spain, Haiti, Argentina, IFAD, UNASUR, UNDP, WFP and IICA). Between 2005 and 2016 in the context of an extended socio-political crisis, deep food insecurity among local populations and recurrent climatic disasters (hurricanes, tropical storms, floods and droughts), about 260,000 people took an active role in growing orchards across very different agroecological regions of the country. In Haiti, the benefit/cost ratio of the agroecological garden project was four-to-one: for each dollar invested, four were obtained in vegetables produce under the self-production system (Díaz 2015). The effectiveness of this approach on targeting food insecurity promoted the development of similar projects in other countries in the region (Guatemala, Honduras) as well as southern Africa (Mozambique, Angola). In Kenya it was shown that households that engaged in both urban farming and urban based rural agriculture are more food secure compared with the non farming households. Urban farming has a potential of improving household food security and provision of fungible income; hence, the practice should be included in the urban food policies (Onyango Omondi et al. 2017).

Cities have often been founded in areas where there is high quality land or good water access, conducive originally to dense farming populations. There are studies that suggest that urban areas will triple by 2030 (UNEP 2014; 2016), and that already, 60 per cent of the world's most productive cropland lie on the outskirts of urban areas. However, urban areas are commonly disconnected from direct relations with the rural areas where food is traditionally produced, as global commodity trade has become a major source of food supplies for urban populations. Recently several efforts have been taken to try to bring locally produced food in nearby areas and supply them, even experimenting with local small-scale urban production schemes. Some have considered a mixed approach between locally produced foods in combination with the acquisition of distant products not found locally (or not in enough amounts for the population numbers involved that must be fed) but always with sustainable schemes. The economic potential of promoting regional and local food systems has been analysed in several parts of the world. In the case of Illinois and its region and its communities, local food systems hold significant potential for economic development (see **Figure 3.15**) and quality of life. Over the last ten years, regional demand for local food has grown 260 per cent, and recent surveys[4] show that three-quarters of Americans prefer that their food is grown locally

Invisible services and flows in local trade and food systems: The invisible services that local trade and food systems support might include: (i) the availability of a diversity of food locally grown under presumably more amicable agricultural practices with lower external inputs; (ii) lower negative impacts on the environment; (iii) fresh produce available seasonally in local markets; (iv) positive inter-relationships between producers, processors and consumers, and a shared construction of knowledge among them; (v) better community ties and a feeling of positive dependency; (vi) more and better quality jobs generated locally; (vii) economic spill over at the community and possibly regional level; (viii) identity preservation among the local communities; (ix) local community networks strengthened; and (x) stronger relationships and social economy with the larger territory (Moulaert and Ailenei 2005), among others.

Positive spill over of trading food produced and/or processed locally also includes variables that relate to the "re-valuation and recognition" of the fundamental role that these diverse "actors" (stakeholders, peoples) have played and continue to play towards the common goal of achieving sustainability. The sense of dignity and meaningfulness of rural livelihoods is strengthened when the result of their work is recognized within their larger community.

Benefits from local trade and food security: Local trade has the potential to generate multiple positive benefits. Bypassing the long international supply chains that characterize the conventional food system could allow local trade to positively influence food security by making food readily available, and potentially lead to a healthier and culturally adequate diet, possibly of higher quality with less spoilage (although this final point is under debate, and it is important to look at the entire food system). For example, it has been brought into question just how "local" is the food sold locally, when the inputs for its production and processing may be sourced from long distances (Plassman and Edward-Jones 2009).

Although the need to achieve food security seems to be mainly linked to low-income countries, urban areas throughout the world can benefit from local trade. Supporting the growth of local markets for urban areas can ensure greater access to fresh fruit and vegetables and otherwise healthy (less processed) food options for large populations, especially those that are the most vulnerable.

Value-addition of local trade contribute can be seen in both environmental and socioeconomic respects. With local trade, the local economy may expand, contributing to food security, human health, reduction in carbon emissions, and local employment. As emphasized by Hinrichs (2000), direct agricultural markets play a key role in creating spaces where consumers and producers can interact face-to face. They produce an arena of exchange that is imbued with more social meaning than conventional retail spaces (Pimbert 2015) while creating stronger community bonds and identity.

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[4] Carried out by United States Farmers and Ranchers Alliance. Findings are reported in Industry Today (2011).

Figure 3.16 Sustainable Local Food System in Chicago (Source: CMAP)

in design

3.4.7 Creating resilience through Eco-agri food systems

Visible and invisible flows currently influence all types of capital globally (human, social, physical and natural) and their interactions, and producing negative and positive effects and flows through time. It is difficult for stakeholders at all points along a food value chain to grasp the implications of invisible flows: for producers, workers, and consumers the impacts of agrochemicals on ecosystem and human health are not thoroughly recognized. Consumer awareness of the health impacts of consuming food enriched with salt and sugar is growing. The performance of different food systems in employing labour, increasing food access and building resilience to shocks are all potential positive value additions that are not always well understood.

Building resiliency in eco-agri-food systems under climate change: IPCC (2014) warns that declining crop yields may already be a fact, and that decreases of 10–25 per cent may be widespread by 2050. FAO (2017b) reports that the degradation of the world's soils has released about 78 billion tons of carbon into the atmosphere. The consensus is that the productivity of crops and livestock may decline because of high temperatures and drought-related stress, but these effects will vary among regions and that solutions come from different approaches and efforts, adapted to local and regional perspectives (FAO 2017b; Hanjra and Qureshi 2010).

Undoubtedly, climate- and weather-induced instability will affect levels of and access to food supply, altering social and economic stability and regional competitiveness. Adaptation is considered a key factor that will shape the future severity of climate change on food production (Altieri et al. 2015). FAO is currently developing six farmer field school (FFS) projects on resilience to climate change, with agroecological approaches, in Africa. For example, the Burkina Faso project aims at enhancing the knowledge of 26,000 people through community-based learning and to contribute to the sustainable management of 15 000 hectares of land. A new global agroecology initiative will be launched in 2018 (FAO 2017b). Other global and regional efforts to promote resilience in the context of climate change include REDAGRES, a network of scientists and researchers located in eight IberoAmerican countries funded by the Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo – CYTED, that shares examples of adaptation to climate change in the agricultural sector.

3.5 CONCLUSION

Nature's goods and services are the foundation of agricultural and food systems. Throughout human history, agriculture has co-evolved and developed within different civilizations, which expanded and diversified food systems. Amongst the different human activities, agriculture demands the greatest amounts of land, water, biodiversity and environmental services in order to maintain stability. Depending on how it is practiced, it can either improve or negatively impact the agroecosystem in which it is embedded. Agricultural systems represent a continuum of models from traditional agriculture to modern agriculture, constantly co-evolving, interacting and influencing each other.

We know that agricultural farming—to produce food crops, animal feed, meat, eggs, milk, fibres and biofuels—has transformed the Earth's capacity to support people, and at the same time has had a significant impact on the habitability of the Earth for the rest of biological diversity.

Agriculture is by far the leading cause of deforestation in the tropics and has already replaced around 70 per cent of the world's grasslands, 50 per cent of savannahs and 45 per cent of temperate deciduous forests (Balmford et al. 2012).

Understanding agricultural and food systems requires an approach that appreciates complexity, where ecological, social, cultural and economic issues interact and influence together in different ways, and take into account the effects of production systems at a landscape scale.

The issue of governance of food security in a globalized world is very complex. It involves multiple layers of decision-making and creates a need for coherent policies. The capacity of single households to ensure an adequate supply of food for its members is affected by both local and global conditions. Decisions that affect the food security of the population of a country involve many social and political forces at multiple levels: the state, businesses, and civil society.

International trade in agricultural goods and the global food system have produced important externalities that have not been fully quantified, or have been assessed only in monetary terms. The analysis of stocks and flows of materials and water and the incorporation of these invisible elements, such as rucksacks and virtual flows, can contribute to a comprehensive understanding of the process in the food chains and to the promotion of a more sustainable use of resources in the eco-agri-food system.

We have seen in this chapter that despite tremendous external forces and economic pressures, traditional and mixed food systems sustain around two-thirds of the global production of commodities and nutrients, and do so within diverse farming landscapes. The potential is substantial, to build on existing food systems, - each with differing attributes- to strengthen forms of agricultural production that explicitly enhance resilience and the natural capital that underpin food systems, creating regenerative forms of agriculture and food that generates multiple positive externalities.

Present global food systems today present distortions that convey both hunger and excesses. It will take investments and efforts on the part of all stakeholders to bring about the radical shift of global agricultural and food systems that is needed. Investment in environmental and nutritional education, together with the promotion to switch to healthy and nutritious diets is essential. Food producers must be socially recognized for their relevant service to the society. Nutritious food, produced with ecosystem services that minimize or eliminate external inputs must be valued for the society for its full benefits and reduced costs.

Governments of countries that aim to restore healthy agricultural systems and promote nutritious and culturally anchored diets must lead the change in global food systems. Corporations also have a role to fulfil, but the shift must be driven by the states. Social organizations of consumers, users, farmers and other NGOs, each with specific social and environmental claims, crucial role to play in changing present social habits at both national and global scales.

Global society – whether taking the perspective of the private sector, governments or civil society - can find in the identification of the intangible and invisible stocks and flow the central elements to understand the integral processes of the complexity of the global food system. Greater insight into these processes can help the public to promote the sustainable use of the natural resources, biodiversity and environmental services in creating eco-agri-food chains with multiple benefits. Public policies, technology and investment possibilities can enhance the promotion towards sustainable food systems, creating opportunities for all farmers, consumers, corporations and countries.

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CHAPTER 4

HUMAN HEALTH, DIETS AND NUTRITION: RECOGNIZING AND INTEGRATING VITAL MISSING LINKS IN ECO-AGRI-FOOD SYSTEMS

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SUMMARY

Chapter 4 outlines ways in which the food system impacts human health - directly or indirectly, negatively or positively – as well as food and nutritional security. It is illustrated how human health is compromised throughout our current food system both for end-point consumers and for those working along the supply chain. This chapter explores a number of endpoints in various food system strategies and creates a context for exploration, mitigation, change, and ultimately transformation of our global food system to one in which health – of humans, ecosystems, and communities – is the norm. We also illustrate ways in which various trends (e.g. climate change, fresh water, demographic shifts) alter the challenge of improving human health via food system activities.

CONTENTS

FIGURES, BOXES AND TABLES

CHAPTER 4

4.0 KEY MESSAGES

- The purpose of this chapter is to explore ways in which current agri-food approaches impact food security, nutrition and human health and to develop options for transforming these systems into eco-agri-food systems that promote human and ecological health.
- Human health is directly linked to and influenced by food and nutrition security, all of which are hugely important (and largely ignored) considerations when evaluating the impacts and externalities of eco-agri-food systems.
- There are five key channels through which food systems negatively impact health: occupational hazards; environmental contamination; contaminated, unsafe, and altered foods; unhealthy dietary patterns and food insecurity.
- Eco-agri-food systems can be either enablers or disablers (i.e. have either positive or negative impacts and externalities) in terms of health and food/nutrition security, depending on a variety of factors that influence what, how and how much food is produced, processed and consumed.
- The challenge to accomplishing sustainable, universal food and nutrition security is multi-faceted and will depend on four interrelated developments: dietary pattern change, social justice, food waste and appropriate technological development.
- Six of the top ten risk factors driving the global burden of disease are diet-related with the quality of life for billions of people impacted by malnutrition.
- Lives and livelihoods can additionally be impacted via food system work-related injuries or deaths or exposure to toxins/pathogens. There are also indirect impacts now and for future generations.
- Population increase, urbanisation and modernisation continue to negatively impact human health and food/nutrition security, for example with 1.9 billion people currently overweigh or obese, whereas more localised, traditional systems can offer important lessons for having positive impacts.
- Harvest and post-harvest management of crops and animal products is critical to ensuring food can be consumed without contamination (chemical or biological) and with minimal losses and decline in nutritional quality.
- Projected dietary pattern shifts – the nutrition transition - will place an unacceptable burden on ecosystems and natural resources as well as chronic disease incidence.
- Several Sustainable Development Goals are directly linked to human health and food/nutrition security, with all of them indirectly linked, and this analysis can be used as part of their ‘toolkit for resolution’.

CHAPTER 4

HUMAN HEALTH, DIETS AND NUTRITION RECOGNIZING AND INTEGRATING VITAL MISSING LINKS IN ECO-AGRI-FOOD SYSTEMS

4.1 INTRODUCTION AND THE TEEBAGRIFOOD EVALUATION FRAMEWORK

Let us start by imagining a future where all forms of malnutrition are eliminated (SDG 2) and we have achieved low levels of obesity/chronic disease globally, with greatly reduced levels of acute disease (SDG 3). The world is composed of connected webs of cooperation across regions, ensuring diversity, resiliency, and global communication (SDG 17). Food systems across the globe provide good livelihoods for those engaged in the production, processing, transportation, storage, and marketing of foods, as well as the management of compostable and reusable waste. The food system is doing its part to eliminate poverty (SDG 1) and provide decent work and economic growth (SDG 8). Women have the same rights and rewards as men in this system (SDG 5), with strong educational institutions (SDG 4) supporting sustainable and healthy consumption patterns. While the majority of people live in urban areas, there are robust urban-rural relationships that ensure food security for all urbanites, while industries supply healthy processed foods, as well as appropriate, responsible technology required in the production, processing, storage, and movement of food supply (SDG 9). Advertising and market placement are skewed to promote healthy dietary patterns, which helps ensure both food and employment security – markedly reducing the threat of urban uprisings (SDG 16), aiding in sustainable city development (SDG 11), and reducing inequalities (SDG 10). The cycle of production and consumption is completed responsibly (SDG 12) with the use of renewable materials and energies – available to all (SDG 7) – and making use of materials and practices that preserve fresh water and provide clean water (SDG 6). Our lands and waters are preserved for humans as well as the flora and fauna we rely upon (SDG 14 and 15). All of this ensures that our global food system does not contribute to increasing climate change – but rather acts as a tool for resolution (SDG 13). In other words, from a human health perspective, the SDGs provide a series of goals, the TEEBAgriFood Framework provides a system for analysis (as outlined in Chapter 6), and a network of food systems embedded in regions across the globe provide a strategy for securing a future for healthy people. This scenario is not feasible or possible without recognizing food as a human right and food security as an entitlement for all people (Sen 1986). In the remainder of this chapter, we show how human health is compromised throughout our current food system, and reciprocally, how human health impacts our ability to engage broadly in society and in the food system itself.

While there are many factors contributing to human health, none has quite the impact of the food we consume. Six of the top 11 risk factors driving the global burden of disease are related to diet (Global Burden of Disease Study 2013 Collaborators 2015). The quality of life for billions of people is impacted by malnutrition (i.e. undernutrition, including deficiencies of essential vitamins and minerals, or by being overweight/obese). Undernutrition, often coupled with infectious disease or parasites, causes stunting, wasting, and diet-related non-communicable diseases (NCDs). Malnutrition associated with diets represents the number one risk factor in the global burden of disease (IFPRI 2016). Globally, maternal and child malnutrition represent the leading cause of disability-adjusted life years (DALY) with dietary risks being the second leading cause (Global Burden of Disease 2016 Risk Factors Collaborators 2017). Malnutrition reduction is not simply a matter of healthy food access – although this is certainly a major contributing factor.

TEEBAgriFood applies a systems thinking approach (see Chapter 2) to understanding the totality of agricultural production, food supply chains, and various institutional policies and practices, which in turn greatly impact an individual's human health as well as their ability to make food pattern changes. The term "eco-agri-food" system is introduced in this report (see chapters 2 and 3) as a descriptive term for the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labor, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food. Across the food system, people are additionally impacted in a variety of ways via work-related injuries (or death) or toxicant/pathogen exposure. Coupled with these direct impacts are indirect impacts, both current and future.

Within the field of public health, the social-ecological model has demonstrated that the interaction between people and their environments is instrumental in shaping individual behaviour (Sallis, Owen and Fisher 2008; Golden *et al.* 2015; Story *et al.* 2008; Golden and Earp 2012), which in turn affects individual and community health outcomes. The food system can either positively or negatively impact food/nutrition security, livelihood procurement, and environmental sustainability across communities. Through the policies, regulatory practices, and social networks that shape the food system, we can see either one outcome where high-calorie, low nutritional content foods are easily procured, or another outcome in which it becomes much easier to consume greater amounts of fruits, vegetables, whole grains, and other healthier foods. In the same vein, we can develop food systems that either allow a relatively large number of individuals to secure a livelihood or one in which large numbers of workers are systematically exploited while a few benefit financially.

The purpose of this chapter is to explore ways in which our eco-agri-food system impacts human health and food and nutritional security, and to explore this as a key point of impact within the context of the TEEBAgriFood Evaluation Framework. This chapter explores a number of endpoints in various food system strategies and creates a context for exploration, mitigation, change, and ultimately transformation of our global food system to one in which health – encompassing that of humans, ecosystems, and communities – is the norm for the 9-10 billion people by 2050, the medium UN population projection for that year. The TEEBAgriFood Framework provides a strategy and process for incorporating a full array of potential health impacts – both positive and negative – into understanding eco-agri-food system best strategies. From production through to consumption, there are myriad methods and practices involved in the food value chain. Each influences the health status of people and the environments in which they live. The TEEBAgriFood Framework examines each link in the value chain to help determine best practices that will optimize community value.

4.2 HUMAN HEALTH – DEFINITION AND SCOPE WITHIN AN ECO-AGRI-FOOD SYSTEM PERSPECTIVE

While the World Health Organization (WHO) definition of health as "a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity" (WHO 1946) was radical for its time, today it seems lacking. Experts have more recently defined health as "the ability to adapt and self manage in the face of social, physical, and emotional challenges"(Godlee 2011; Huber *et al.* 2011). In order for this to happen, people must be food- and nutrition-secure. Food and nutrition security "exists when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life" (Committee on World Food Security 2012). In order for individual food security to exist, we argue that community food security across the global community is a necessary precondition. Community food security has been defined as a scenario where "all community residents obtain a safe, culturally acceptable, nutritionally adequate diet through a sustainable food system that maximizes community self-reliance and social justice" (Hamm and Bellows 2003; Bellows and Hamm 2003). We know of no community globally that would meet this definition.

Looking in the broadest terms, there is wide disparity in human health across the globe. Although a poor surrogate for health, global life expectancy gives some idea of these global disparities. Global life expectancy at birth in 2015 was 71.4 years (73.8 years for females and 69.1 years for males), ranging from 60.0 years in Africa to 76.8 years in the Europe (WHO 2017e). Healthy life expectancy (HALE, which takes morbidity into account, as life expectancy does not) (WHO 2014b) varies markedly at birth from a low range of 29.5-37.3 years in many African countries to 67.9 to 73.8 in a number of developed countries (Mathers *et al.* 2001).

These variations are due to a number of causes - non-communicable disease (NCD) being one very important contributor. Both undernutrition and being overweight or obese (as well as a host of other factors within and outside the agri-food system) play a role in whether an individual develops NCDs (Nishida *et al.* 2004; Darnton-Hill *et al.* 2004). Influences contributing to NCD development are part of a continuum, i.e. risks begin in fetal life and continue into old age (Nishida *et al.* 2004). For example, poor nutrition in utero and in infancy can lead to stunting and impaired neural pathway development affecting a person throughout life. NCDs suffered in adulthood reflect, in part, cumulative differential lifetime exposures to various damaging environments in concert with individual genetic predispositions. The criteria are now better recognized and occur at a far higher rate in the populations of the developing and transitional worlds (WHO and International Longevity Centre - UK 2000).

We most typically consider health impacts in respect to supply-chain endpoint consumers. Unhealthy dietary patterns where excess calories are easily accessible is a risk factor in the etiology of several leading causes of mortality and morbidity (Institute of Medicine and National Research Council 2015) and greatly impacts the global burden of disease (Global Burden of Disease 2016 SDG Collaborators 2017). Mortality and Disability Adjusted Life Years (DALYs) lost are impacted by various diseases, some arising from issues related to food consumption (Global Burden of Disease 2016 Risk Factors Collaborators 2017).

Three metabolic factors are at least partially attributable to dietary patterns – high systolic blood pressure, high fasting plasma glucose, and high body-mass index - account for the largest number of metabolically attributable DALYs globally (Global Burden of Disease 2016 Risk Factors Collaborators 2017). Across the supply chain, occupational hazards, environmental contaminants, and pathogenic/parasitic exposures also contribute to DALYs, in addition to unhealthy dietary patterns and undernutrition of various types (IPES-Food 2017). These issues will be explored in more detail below. For now, consider the array of hazards, contaminants, and exposures that both workers within the food supply chain and food consumers are subject to: farmers, farm workers, and supply chain workers experience a number of workplace hazards related to work conditions, institutional policies, and social norms. Consumers are similarly exposed to a range of hazards and contaminants and may also have a co-existing disease/parasitic infection and/or lack access to foods that enable healthy dietary patterns.

4.3 SUSTAINABLE DEVELOPMENT GOALS, HEALTH AND THE ECO-AGRI-FOOD SYSTEM

The 2030 Sustainable Development Agenda has 17 Sustainable Development Goals (SDGs) and provides an opportunity to build better systems for health in part by recognizing that health depends upon and supports productivity in other key sectors such as agriculture, education, employment, energy, the environment, and the economy (WHO 2017e). Therefore, health contributes to and benefits from all the other SDGs (UN GA 2015), and if achieved, the SDGs will also strengthen a number of determinants of health, such as gender equity and education.

Accounting for the food system as both the means of provisioning good nutrition and a recipient of positive nutrition and health outcomes (e.g. greater labour productivity) is reciprocally necessary in order to achieve the SDGs UNSCN 2015). The UN General Assembly declared 2016-2025 as the Decade of Action on Nutrition, specifically referencing the Rome Declaration on Nutrition (FAO and WHO 2014b) and its Framework for Action (FAO and WHO 2014a) with sixty recommendations. These documents specifically address the need for sustainable food and agricultural systems. For example, the Rome Declaration states, "food and agriculture systems, including crops, livestock, forestry, fisheries and aquaculture, need to be addressed comprehensively through coordinated public policies, taking into account the resources, investment, environment, people, institutions and processes with which food is produced, processed, stored, distributed, prepared and consumed". Some recommendations specifically address components of the food system while others address the institutions, policies, and practices that govern (or fail to govern) it. The adoption of the 17 Sustainable Development Goals and the declaration of the Decade of Action provide a set of global targets that dovetail well with the TEEBAgriFood Evaluation Framework.

Considering the source of food products, the supply chains involved in moving food products from growth and processing to the consumer, and various retail points that convey goods to the end user, there are four overlapping and intersecting types of food systems in any community (Gomez and Ricketts 2013) that we will use for the purposes of this discussion. These can be framed as:

- Traditional
- Traditional-to-modern
- Modern-to-traditional
- Modern

In other words, food can be grown and produced within the region and enter either a traditional supply chain with a retail point-of-sale that is, for example, a traditional market (traditional), or a retail supermarket (traditional-to-modern). On the other hand, a highly processed product (e.g. soda) can originate via a global supply chain and end either at a traditional market (modern-to-traditional) or a retail supermarket (modern). These are admittedly very broad, brushstroke framings for a typology, but will suffice for our purposes.

At the beginning of this chapter an aspirational scenario was presented linking all the SDGs and outlining ways in which the eco-agri-food system could positively impact them all. A consideration of the 17 SDGs, in their entirety, couples nicely to the TEEBAgriFood Framework, but two SDGs are the most congruent with the discussion of health and the food system: SDG 2 (zero hunger) and SDG 3 (good health and well-being). SDG 2 has eight targets focused on various aspects of agricultural production and hunger/malnutrition targets. While SDG 3 does not explicitly include food, a number of the targets are dependent upon a well-functioning human immune system, which inherently requires consumption of a healthy diet on a daily basis. SDG 3 aims to ensure healthy lives and promote wellbeing for all across their lifespan, and it has 13 specific health targets with target 3.4 focused specifically on reducing premature mortality from NCDs by one-third.

4.4 POPULATION INCREASE AND URBANIZATION IMPLICATIONS FOR HEALTH, FOOD SECURITY, AND SUSTAINABILITY

The growing world population is a crucial factor when examining the future of the food system. Population increases matter not only when it comes to global carrying capacity but also per capita environmental impact in specific geographic locales, and discrepancies in factors like education and fertility (Crespo Cuaresma*et al.* 2014). How we react to the burden of more people globally – as countries, as communities, and as individuals –will determine much of how the future unfolds.

Numbers illustrate only one part - but an important part - of the story. Estimates vary but a global population of 9.8 billion by 2050 and 11.2 billion by 2100 is likely – with a 95 per cent confidence range of 9.4-10.2 billion in 2050 and 9.6-13.2 billion in 2100 (UN DESA 2015) Could 9.8 billion people, predominantly living in urban areas, be fed sustainably and consume healthy, culturally secure meal patterns? The simple answer is: it depends.

The vast majority of the global food supply is currently produced by rural farmers. How much of the world's food supply is produced by small holder farmers is contested with "70%" the oft-cited number[1]. More than half of the world's population now lives in urban areas (see **Figure 4.1**) – and movement to urban areas will continue as manifested by projected growth in cities of all sizes. As the 21st century unfolds, rural farmers will need to supply a greater number of consumers per capita to ensure food security and a daily healthy diet. At the same time, larger numbers of people are further from the points of food production and supply chains than in the past. Infrastructure needs to expand to ensure food security for urban numbers approaching 66 per cent of the global population by 2050 (UN DESA 2015). In low-income countries across the globe, the incidence and percentage of rural poor is higher than urban poor (Alkire *et al.* 2014), and the largest percentage of these rural inhabitants are farmers. At the same time that demands on farmers are increasing in terms of food production, the rural population is aging (as many youth migrate to urban centres), and experiencing significant inequality when it comes to their own food security and other measures of well-being. This results in a growing inequality, where rural farmers are living alongside and supplying food to urban populations that are overconsuming calories and other resources (leading to higher obesity rates and other health issues), potentially resulting in civil unrest.

The previously posed challenge to accomplishing sustainable, universal food and nutrition security is multi-faceted – moving from "it depends" to "yes" will depend on four interrelated developments:

1. Dietary pattern change: On average, the more meat and dairy products consumed per capita, the more land, fertilizer, and water required for production.

2. Social justice: The distribution of food is currently much more problematic than the absolute amount of food produced. In addition, achieving gender equity could unleash tremendous human development potential – much of it directed at food production and/or food system livelihoods.

3. Food waste: Cutting waste significantly across the globe could have a significant impact on food security and future production needs.

4. Technological development: The ability of small holder farmers to increase productivity without increasing labour could be a key to food security in urban areas. Enhanced agroecological strategies coupled with improved labour-saving equipment is critical.

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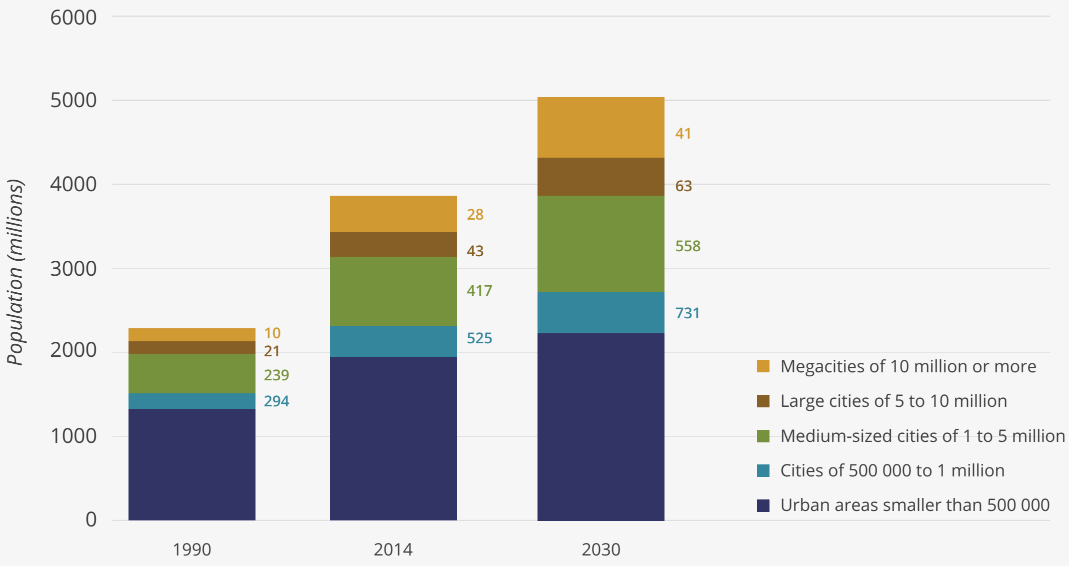
[1] For an interesting discussion of the generative nature of '70% of the world's food is produced by small holder farmers" see: https://www.researchgate.net/post/Smallholder_farmers_produce_70_per_cent_of_the_worlds_food_Whats_the_source_for_this_number

Figure 4.1 Global urban population growth is propelled by the growth of cities of all sizes (Source: adapt from UN DESA 2015)



The TEEBAgriFood Framework provides a strategy for examining these four dimensions. In this section we look at each of these in a bit more detail relative to environmental sustainability.

Dietary Patterns: Current dietary patterns for much of the developed world are not sustainable and will be if environmentally very deleterious if continued and expanded globally (Nelson *et al.* 2016). This is especially true of growth in meat supply as seen in **Figure 4.2.**

Per capita meat consumption varies from 4 kg/year in India to 117 kg/year in the U.S. As seen in **Figure 4.2**, the global per capita consumption has increased from 23 to 42 kg/year between 1962 and 2009. If 9.7 billion people were to eat like a typical American., it will require approximately an additional 309 billion kilograms of edible meat production per year; this is about 1.2 billion more cattle if all came from beef, or 161 billion more chickens if it all came from poultry (in both cases using average slaughter and edible meat rates for typical U.S. production but without accounting for food waste[2] . Even at very high per-acre feed yields, this would require vastly more land (Meeh 2011)– 1.59 billion hectares if all beef or 184 million hectares if all broiler chickens. With about 49 million km^2 of global agricultural land (World Bank Data) (about 4.9 billion hectares), this would imply a 36 per cent increase in agricultural land for cattle production or a 4.2 per cent increase for broilers (at Michigan, USA feed production/hectare levels, an optimistic assessment and without accounting for wasted food). This would only happen at great expense to currently forested lands, which would require clearing in order to grow feed, with severe repercussions regarding greenhouse gases (GHGs), biodiversity and water pollution.

That said, some have argued that shifting ruminants to management-intensive grazing, a strategy of high density grazing with frequent movement, would result in net carbon sequestration and a shift for ruminant production from a net GHG emitter to a net GHG sequester thanks to alterations in the soil and plant/plant root dynamics in these grazing areas (Teague *et al.* 2016; Stanley *et al.* 2018). It would also reduce sediment and nutrient runoff. It is not clear, however, for how long these effects would be seen; there is reasonably an asymptote to the total carbon sequestration per hectare. No matter how ruminants are produced, the *amount* of meat consumed in most of the developed world is environmentally unsustainable and related to negative health outcomes including cardiovascular disease (Potter 2017), and if adopted by 9.7 billion people would be very problematic – the quantitative per capita level is critical to the balance of human nutrition and environmental sustainability.

There is a strong nutrition transition occurring globally (Popkin *et al.* 2012; Popkin 2017) – one facet of which is increasing per capita meat consumption – and it is not practical, feasible, or sustainable for the global population for this trend to continue. Garnett and Strong (2012), on behalf of the Green Food Project and building on the work of many including McMichael *et al.* (2007), have suggested principles of healthy and environmentally sustainable eating that include:

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[2] Calculations based on Meeh *et al.* (2013) study in Michigan, USA

- Moderating meat consumption, and increasing intake of peas, beans and other pulses, tofu, nuts, and other plant sources of protein.
- Decreasing the amount of milk and dairy products in diet and/or seeking out plant-based alternatives, including those that are fortified with additional vitamins and minerals.

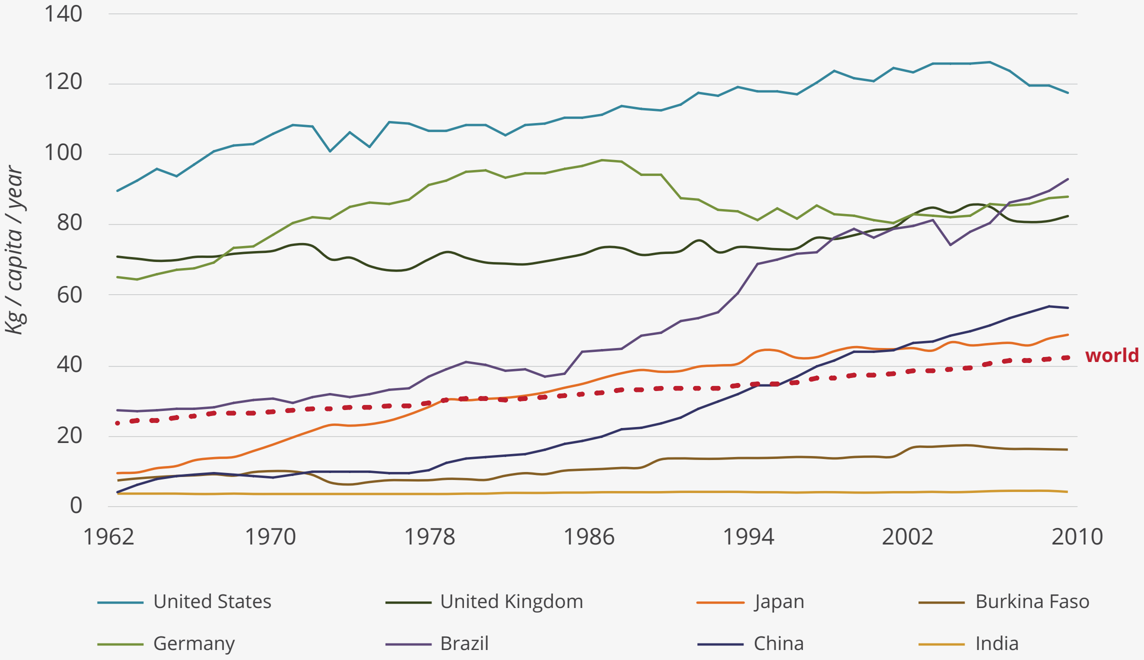
One underexplored avenue that is gaining traction is the use of insects as a protein and micronutrient source (van Huis *et al.* 2013). FAO suggests a number of benefits environmentally, nutritionally, and socially including their high feed conversion ratio with low land use as well as high nutritional content (Halloran and Vantomme 2014). While a number of cultures have long included insects in their dietary patterns, only recently is the practice gaining traction as a potential global food source. Researchers caution that while it appears that raising insects for food generates a much lower environmental footprint than other creatures there is a need for more extensive life cycle analysis (Halloran *et al.* 2016) as well as other research (Halloran *et al.* 2015).

Social Justice: What aspects of a food system encourage greater social justice? Do the structure and relationships underlying certain typologies tend towards greater social justice? The research is clear that an important component in malnutrition is women's status in a given society (IFPRI 2016).

In the developed world, there is evidence that a combination of community-based solutions and governmental policies can help move us towards greater dietary diversity – and hence healthier diets. Evidence of enhanced food security is not yet evident as most of the case examples are too small and locally restricted at this point. But by means of example, in the U.S. wireless technology has allowed for the use of food stamps at farmers' markets. This, coupled with state government cost support, has rapidly escalated access to fresh produce by low-income households (Smalley 2014). In addition, a further expansion of access has occurred through the development of "Double-Up Bucks" programs across the country (Fair Food Network 2017). This program started with philanthropic funds in a few states and has now expanded to 23 of the 50 U.S. states. It doubles the value of a customer's food stamps for fresh produce. Importantly, it was incorporated into the last U.S. Federal Farm Bill to provide grant funds annually for the creation and management of these programs. These largely run via regional supply chains (final point-of-sale are typically farmers' markets).

Outside the U.S. there are a wide range of social justice programs focused on aspects of the food systems. These are extensively outlined in Chapter 5.

Figure 4.2 Development of meat supply over time (Source: adapted from Stoll-Kleemann and O'Riordan 2015)



Food Waste: FAO estimates that approximately 32 per cent (on a weight basis) of all food is wasted (Lipinski *et al.* 2013). This topic is approached in more detail in Section 4.10. With population growth and urbanisation it is even more critical to reduce wasted, edible food in order to improve nutritional status and reduce environmental stress.

Appropriate Technology: Appropriate technology development in service of farmers and others in the food supply chain is critically necessary as populations urbanize. Whether in the developed or the developing world, small-scale farmers share the problems of access to markets, access to credit, the need for improvements in agroecological farming, and demand for increased production without a near-linear increase in labour requirements, all without a resultant increase in GHG release.

Using Africa as an example, it has become a net food importer (Rakotoarisoa *et al.* 2011), a fact primarily driven by population growth. This population growth since the late 1990s has primarily occurred in urban areas with the rural population fairly static, but aging. Reversing Africa's food import status would require the rural farming population to become more productive, i.e. to produce more food per capita and/or create less waste. One aspect of this would be the increased use of mechanization, powered by renewable sources of energy. There are several promising technological developments that could help, including increasingly cost competitive rural renewable power charging hubs. Electric tractors are under development (see Solectrac website (2018)) with potential for improving the efficiency of small-scale farmers across the globe. In the context ofthe TEEBAgriFood Evaluation Framework, it must be asked: are the improvements that such technology enables better suited for smaller-scale, more regionalized production, or would they also provide benefits at the larger scale of globalized production where far greater horsepower is needed? Can policies and support mechanisms be developed so that technologies such as these become widely available and usable by small-scale farmers?

As described earlier, there are several possible pathways to supply food for an increasingly urban world. Urban development can build on pre-existing traditional markets and ensure that whole foods required for health are available in sufficient amounts and of high quality for consumers. These smaller markets, while also offering highly and moderately processed foods, tend to have a high proportion of raw foods. An alternate route would be supporting large numbers of supermarkets at the expense of traditional markets with regional supply chains. This model, one espoused by much of the developed world, means high-sugar and high-fat (i.e. high caloric density) foods will be plentiful and less costly than nutrient-dense foods (Drewnowski and Specter 2004). Researchers (Rischke *et al.* 2014; 2015; Kimenju *et al.* 2015) have identified the proliferation of supermarkets in both rural and urban Kenya as a strong contributing factor to the increasing obesity rates due to the availability and relative affordability of high-calorie, highly processed foods. They suggest that supermarkets are associated with the nutrition transition and the emergence of obesity in small Kenyan towns and a higher body mass index among adults. The trend is not observed in children and adolescents, where it seems to reduce their undernutrition.

4.5 OVERCONSUMPTION: A CRITICAL THREAT TO HUMAN AND ENVIRONMENTAL HEALTH

Our food system and associated dietary patterns impact the environment in a variety of ways, and what and how much we eat impacts how rapidly we reach planetary boundary limits – including excess greenhouse gas emissions, biodiversity loss, water quality degradation, water availability, land use patterns, and landscape degradation.

Excess calorie and/or excess protein consumption is the most obvious and arguably the most environmentally impactful of our dietary patterns. Current Western-type diets, with high intakes of meat, fat and sugar represent a major risk to health, social systems and environmental life support systems (Aleksandrowicz *et al.* 2016; Global Panel on Agriculture and Food Systems for Nutrition 2016; European Commission Standing Committee on Agricultural Research 2011; Lim *et al.* 2012). The average person in more than 90 per cent of the world's countries had daily per capita protein consumption that exceeded estimated dietary requirements in 2009 (Ranganathan *et al.* 2016). While 465 million people were reported as underweight in 2014 (WHO 2018c), 1.9 billion adults were overweight (including obese) (WHO 2016b). Most of these overweight or obese are in the developing world (Keats and Wiggins 2014), showing how deeply a nutrition transition leading to Western-pattern diet adoption has permeated. In the U.S., the average person consumes about 2,200 total calories daily (USDA 2014). For women there has been an average increase of about 335 calories per day, and for men about 168 calories per day between 1971 and 2000 (Wright. *et al.* 2004)[3].

To give a sense of the excess production (and attendant drain on natural resources) required for this level of

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[3] It is assumed these are excess calories – mostly in the form of sugar and fat – since the U.S. obesity rate was very low in 1971 and increased markedly during this period.

consumption, let us assume for a moment these calories come from high fructose corn syrup and corn oil (which are indeed among the most over-consumed products). Industry can extract about 42,100 calories of high fructose corn syrup and about 6,200 calories of corn oil per bushel of corn. In this scenario[4], assume corn production of 420 bushels per hectare (Nielsen 2017) – the approximate average U.S. production in 2016. Excess consumption over 325 million U.S. residents with 126 million adult women and 120 million adult men means that a minimum of 1.1 million hectares of corn production is needed just for direct excess calorie consumption (there are about 36.4 million hectares grown in the U.S.). These extra hectares lead to soil loss, phosphorus runoff, and nitrogen contamination of water wells for rural residents, and loss of wildlife habitat.

If we extrapolate this to the world, 7.6 billion people consuming that many *extra* calories implies a need for about 94 per cent of the total U.S. corn production, a conservative estimate for several reasons. First, this calculation assumed direct calorie consumption of vegetable-based products as opposed to consumption of animal-based calories with attendant inefficiencies. Second, while many of these excess calories are consumed, a percentage is lost as wasted food - the food wasted, with the extra calories available, is not accounted for in these calculations. Third, in the global calculations U.S. average corn yields are used. Average global corn yields are about half the U.S. average, requiring closer to 66 million hectares of corn production to grow the extra calories if none are lost in the supply chain – a good deal more when losses are considered.

Economic development, globalization, urbanisation, and changing lifestyles are linked to a shift towards poor-quality diets, excess caloric intake, and low levels of exercise, leading to a rapid increase in obesity and NCDs globally (Hawkes 2006; Kjellstrom *et al.* 2007). These consumption patterns are related to the food system type/structure in which food consumers exist, as well as changes in income status.

4.6 AGRICULTURE'S ROLE IN A HEALTH-PROMOTING FOOD SYSTEM

The food system starts with agricultural production and the range of inputs supporting it. Without production there is no food. The quality and type of food and diets available is both a result of what agriculture is producing and how such production is being undertaken (Fanzo *et al.* 2013) as well as the transformation of crops into processed foods. Agriculture has significantly changed in the past century from a system where diverse farms produced a wide variety of crops and animals to one marked by more and more specialized farms producing one or a few major crops, especially cereals and feed crops. Industrialized agriculture has not only transformed the agricultural landscapes in high income countries and economies in transition, but is also the dominant model being promoted in agricultural development programs in low-income countries (IPES-Food 2016).

The rise of industrial agriculture has had impacts on the nutrient content of diets. Indeed, agricultural policies that promote specialization in energy-rich staple cereals have corresponded with a decline in consumption of pulses and other minor crops with high nutritional value (Hawkes 2007; DeFries *et al.* 2015). Industrial agricultural systems have never been explicitly designed to promote human health and, instead, primarily focus on increased productivity and profitability for farmers and agricultural industries (Bouis and Welch 2010). Breeding programs for the major crops have focused mainly on productivity increases (Haas *et al.* 2016). The result of this evolution has been the production of large quantities of relatively inexpensive energy-rich, nutrient-poor food that represents an increasing proportion of food intake.

For instance, data indicates that winter wheat yield increases are concurrent with decreases in selenium, zinc, and iron content (Fanzo *et al.* 2013; Garvin *et al.* 2006). Between 1950 and 1999, 43 garden crops have shown declines for six nutrients (protein, Ca, P, Fe, riboflavin, and ascorbic acid). Those showing median declines ranged from 6 per cent for protein to 38 per cent for riboflavin (Davis *et al.* 2004). This will likely be exacerbated by climate change with additional losses in crop nutrients (Myers *et al.* 2017).

Global land area devoted to high-yielding cereals increased over the past 50 years, with rice, wheat, and maize collectively increasing from 66 per cent to 79 per cent of all cereal area between 1961 and 2013. This was at the expense of other cereals, many with higher micronutrient contents: barley, oats, rye, millet, and sorghum collectively declined from 33 per cent to 19 per cent of total production (FAO 2018). The iron content of millet is nearly four times that for rice. Oat zinc content is more than quadruple wheat (DeFries *et al.* 2015).

In the last decade, increasing awareness of the crucial role that agriculture can play in improving the nutritional quality of food and diets has led to the notion of nutrition-sensitive agriculture, a concept that aims to narrow the gap between available and accessible food and the food needed for a healthy and balanced diet for all people (Jaenicke and Virchow 2013). Two main tracks have been followed: biofortification and diversification.

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[4] Calculations in this section are by the Coordinating Lead Author.

Biofortification is the process of increasing the density of micronutrients such as pro-vitamin A, iron, and zinc in crops through plant breeding, transgenic techniques, or agronomic practices. Biofortified staple crops, when consumed regularly, have been reported as generating measureable improvements in human health and nutrition (Bouis and Saltzman 2017). The CGIAR-led "Harvest-plus" program, later morphed into the Agriculture for Nutrition and Health Programme, made significant investments in biofortification of some major staple crops (Anderson *et al.* 2017). Examples include iron-rich crops, vitamin A-rich crops, and zinc-rich crops. One major limitation of biofortification in improving nutrition and health is that it addresses only one or two micronutrients per crop, which is helpful, but not compensatory to the general decrease in nutritional density of modern varieties of staple crops.

Within a TEEBAgriFood Framework, we would posit that diversification of production (and hence the potential for diversification of diet) is a more community-centred approach to improving dietary potential than industrial agriculture offers, and one that promotes exposure to a broad mix of nutrients and non-nutritive organic compounds which have antioxidant, anti-cancer and other beneficial properties (Fanzo *et al.* 2013). In recent years, there has been increasing evidence of the nutritional benefits of diversification of production systems. A study using data from household surveys, after controlling for household characteristics, to estimate the effects of crop diversification on nutrition (dietary diversity) and on income (crops sold) of rural households from eight developing and transition economies has shown a positive correlation between the number of crops cultivated, household income from crops, and two indicators for dietary diversity (Pellegrini and Tasciotti 2014). Similarly, a study surveying farm households in India identified a causal link between dietary diversity and farm-level diversification (Chatterjee 2016), and crop diversification was found to positively influence dietary diversification in Zimbabwe (Chinnadurai *et al.* 2016). It has been argued that diversification of production systems and the market supply of this enhanced diversity will only happen in the developing world when the current distortions to farm- and market-level incentives are corrected (Pingali 2015) and policies supporting diversification are implemented. Unfortunately, investments in greater use of agricultural biodiversity have been insignificant in comparison to investments in biofortification (Toledo and Burlingame 2006).

Another area of increasing interest in terms of moving away from industrial agriculture is that of urban agriculture. Urban agriculture has evolved irregularly over time, with significant increases in periods of crisis, such as during and immediately after World War II, but decreases in periods of relative peace. In the last few decades the growing problem of food insecurity in cities, especially in the wake of the 2007-08 food price spike, has meant the development of many new initiatives supporting urban agriculture.

There is still no consensus on the precise definition of urban and peri-urban agriculture, but it can be defined broadly as the growing of plants and the raising of animals for food within and around cities. It typically uses urban resources (such as organic waste as compost and urban wastewater for irrigation), urban residents as labourers, and has a direct link with urban consumers. It directly impacts urban ecology, in part through competition for land with other urban functions. It is greatly influenced by urban policies and plans (Chinnadurai *et al.* 2016). The activities may take place on the homestead (on-plot) or on land away from the residence (off-plot), on private land (owned, leased) or on public land (parks, conservation areas, along roads, streams, and railways), or semi-public land (schoolyards, hospital grounds).

There are a number of ways through which urban agriculture can, in principle, have an impact on urban food security. At the household level, urban agriculture can be a source of income, can provide direct access to a larger number of nutritionally rich foods (vegetables, fruit, meat) and a more varied diet, can increase the stability of household food consumption by providing a bulwark against seasonality or other temporary shortages (Zezza and Tasciotti 2010). The motivations for engaging in urban agriculture are often quite different in the global north and developing countries. Heynen *et al.* (2012) describe urban agriculture in North America as "a deliberately political action and a way to reclaim spaces that have become dominated through the interests of capital and other corrupting social power relations". In the U.S., urban gardening also has been suggested as an effective tool for enhancing social cohesion and bridging racial divides by bringing people from different ages, races, and income levels together (Shinew *et al.* 2004; Blaine *et al.* 2010). In the sub-Saharan African context, attention to urban agriculture tends to stress the practice's potential as a food security or poverty alleviation strategy (Battersby 2013).

Urban agriculture has become a key component of food and nutrition strategies for the poorer segments of the urban population. A large percentage of the people involved in urban agriculture are the urban poor. In sub-Saharan Africa, for example, it is estimated that 40 per cent of the urban population is engaged in agriculture (Reed 2014), while in Vietnam, it can be as high as 70 per cent (Zezza and Tasciotti 2010; Orsini *et al.* 2013). Women constitute an important percentage of urban farmers (Musiimenta 2002; Hovorka *et al.* 2009), since agriculture and related processing and selling activities, among others, can often be more easily combined with their other tasks in the household (Resource Centres on Urban Agriculture and Food Security Foundation 2009).

Some reports estimate that 800 million people worldwide are engaged in urban agriculture, with between 100 and 200 million producing for the market (FAO 1996; Armar-

Klemesu 2000) FAO. However, at the global level, there are still no reliable quantitative data on the total number of people involved in urban agriculture or on its contribution to urban food security. A recent study estimates that urban agriculture contributes 100-180 million metric tons of food per year (Clinton *et al.* 2018). It seems clear, however, that in some cities urban agriculture is an important coping strategy for households and makes a significant contribution to improving food security. Self-grown food can contribute to household food security both through direct provisioning and through the sale of produce on the market, generating cash that can be used to purchase food – more so in Latin America than in Africa (Ellis and Sumberg 1998; Maxwell 2003).

Simply put, urban agriculture plays many roles beyond food provisioning (WinklerPrins 2017). In many cases, the quantity of food produced is secondary to community aspects of the endeavour. Still, the global and regional extent of urban agriculture needs to be quantified far more rigorously (Hamilton *et al.* 2014), something a food system approach is much more capable of tackling than more narrow approaches on productivity or supply chains. The current trends of urban agriculture across the developed world indicate that the practice is growing and evolving as crises emerge and fade (Mok *et al.* 2014). Although easier access to safe and nutritious food (mainly fresh products) helps improve health conditions of the urban poor, Orsini *et al.* (2013) have listed a set of potential health concerns related to urban agriculture:

- Contamination by pathogens that results: (a) from irrigation with polluted water, (b) inappropriate use of organic fertilizer (e.g., fresh animal and human waste or non-composted urban wastes that are in direct contact with edible parts of the plants), and (c) poor hygienic practices during post-harvest and handling activities (transport, transformation and marketing)
- Contamination as a consequence of inappropriate use of pesticides and difficulty disposing of obsolete or expired stocks
- Contamination of soil and products with heavy metals as a consequence of agricultural production along roads with high traffic or near industrial discharges
- Disease transmission to humans from animal production (bird flu, tapeworm)
- High occurrence of insects/disease vectors (e.g., mosquitoes, for which urban agricultural activities could provide a more water-rich breeding environment) (Klinkenberg *et al.* 2008).

Despite multiple environmental and social benefits to promoting urban agriculture within cities, doing so remains challenging in the face of other urban processes. Identifying win-win areas for urban farming, where environmental and social benefits can be maximized on otherwise unused land is necessary and possible to build support and acceptance for these urban farming systems both socially and politically (Lin *et al.* 2017).

In the developing world, there are two opposing trends. On the one hand, the pressure of increasing urban populations leads to loss of land in cities and around them where urban agriculture can be practiced. On the other hand, initiatives to support and expand urban agriculture are emerging in many cities of the South making significant contribution to urban nutrition.

In response to massive population growth, new cities are being planned and built, and existing cities drastically modified, so the opportunity exists for urban agriculture to be included in food systems in an organized rather than an informal manner (Hamilton *et al.* 2014).

4.7 FOOD SYSTEM HEALTH IMPACTS – OCCUPATIONAL HAZARDS, ENVIRONMENTAL CONTAMINATION, AND PATHOGENIC CONTAMINATION

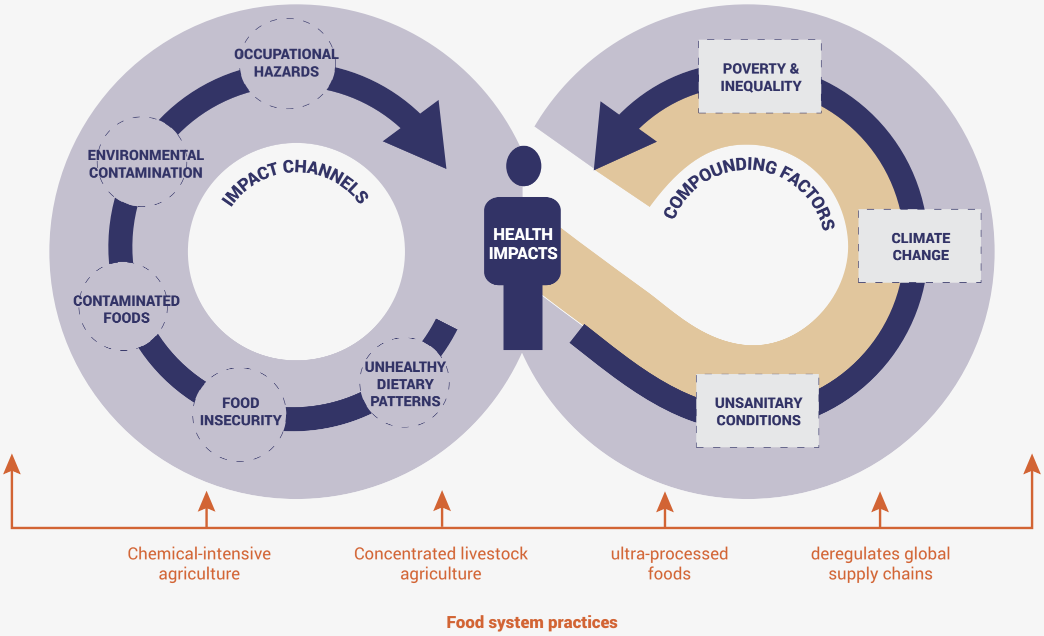
IPES-Food (2017) has identified five key channels through which food systems negatively impact health: occupational hazards; environmental contamination; contaminated, unsafe, and altered foods; unhealthy dietary patterns; and food insecurity – see **Figure 4.3**.

Three of these issues will be explored in this section: occupational hazards, environmental contamination, and pathogenic contamination.

4.7.1 Occupational hazards

The agricultural sector is one of the most hazardous workplaces in which to be employed worldwide (Cole 2006; ILO 2009; The Food Chain Workers' Alliance 2012; IPES-Food 2015). While lack of data is a problem, it is nonetheless known that millions of injuries occur annually to agricultural workers, with at least 170,000 of these resulting in fatalities (Cole 2006). In the U.S., the occupational fatality rate for workers in agriculture, forestry, and fishing from 2006-09 was significantly higher than for all other industries (Institute of Medicine and National Research Council 2015).

Figure 4.3 Understanding health impacts in a food systems context (Source: adapted from IPES-Food 2017)



Sites of agricultural production and fisheries have characteristics that jeopardize safety and health: exposure to extreme weather, close contact with animals and plants that could cause injury, extensive use of agro-chemical and biological products, difficult working postures and lengthy hours, and use of hazardous agricultural or fisheries tools and large machinery. These factors have been commonly documented and associated with a range of health conditions from simple heat stress to complex diseases such as cancer. Increased rates of respiratory diseases, skin disorders, certain cancers, poisoning by chemicals, neurological disorders, infertility, and heart-related illnesses have been documented (Rein 1992; Anderson and Bama 2015).

Pesticides are one source of health risk for farmers, agricultural workers and their children; workers on conventional (non-organic) farms are most affected by pesticide exposure due to their constant, long-term contact (Blainey *et al.* 2008). Acute unintentional (accidental) and intentional (suicidal) pesticide poisoning is common (Cole 2006; Eddleston *et al.* 2002; Gunnell *et al.* 2007). Even cases of acute pesticide poisoning are not always recorded by health authorities, though it has been estimated that 2 to 5 million people every year suffer from such acute poisonings (Cole 2006). The number of deaths from accidental pesticide poisoning deaths is unknown – while many have put the number at 200,000 this is likely inaccurate since statistics for pesticide-related toxicity are not well captured (National Institute for Occupational Safety and Health 2011; Geiser and Rosenberg 2006).

The overall incidence of poisoning events in the U.S. was reported as 53.6/100,000 farm workers compared to 1.38/100,000 for non-farm workers (Calvert *et al.* 2008). About one-third of the affected workers were pesticide handlers; the rest were farm workers exposed to off-target drift of pesticide applications or exposed to treated plant or animal material. In developing countries, which account for only 25 per cent of pesticide usage, incidents often occur during application in the field because protective clothing is too expensive, damaged or cumbersome and uncomfortable in hot climates (Eddleston *et al.* 2002). In addition, safety precautions may not be understood because of language barriers, illiteracy, or a misinterpretation of pictograms (PAN-Germany 2012). Incorrect handling, storage at home, and disposal of pesticide containers are further risk factors (Konradsen *et al.* 2003). In many parts of Asia and Latin America, pesticide consumption is also a frequently used means of suicide due to the substances' easy availability and lethality (Gunnell *et al.* 2007).

Although still contested by some, evidence shows that lower-dose, chronic exposure to many pesticides is linked to many long-term health effects, even when using correct safety procedures (Human Rights Council 2017). Endocrine disruptor chemicals (EDCs) in pesticides can cause detrimental and transgenerational effects to the embryonic development of the fetus during pregnancy, leading to: both birth defects and developmental disorders; an increased risk of various types of cancer; disruption of the endocrine system, which includes interference of the body's production, release, and elimination of natural hormones as well as damaging effects to the immune system; neurological problems and cognitive disability; and respiratory distress (Blainey *et al.* 2008; Gilden *et al.* 2010). The direct link between pesticides and some of these conditions is contested because of insufficient funding for research, a sufficiently long lag between exposure and illness making causality difficult to demonstrate, and synergisms among chemicals can be difficult to analyze.

Injury is also common on farms, fishing vessels, and in industrial food production and processing operations (Goldcamp *et al.* 2004; Lindsay *et al.* 2004; McCurdy *et al.* 2004; Carlson *et al.* 2005; Jones and Bleeker 2005; Pickett *et al.* 2005; Cole *et al.* 2006; Marlenga *et al.* 2006; Solomon *et al.* 2007; Sosnowska and Kostka 2007). The most frequent injuries included sprains, strains, broken bones, crushes, hearing loss from operating noisy machines and engines. Truck drivers, many of whom transport food items, suffer high fatality rates (Forkenbrock 1999). High rates of injuries are also reported for concentrated animal feeding operations (CAFOs)(Mitloehner and Calvo 2008).
The high-pressure work environments of industrialized food processing plants, where work is performed over long periods of time at a fast pace, and in extreme environments (such as refrigeration rooms), put workers at an increased risk for frequent injury (Chiang *et al.* 1993; Kaminski *et al.* 1997; Campbell 1999; Grzywacz *et al.* 2007; Lloyd and James 2008; Sormunen *et al.* 2009; The Food Chain Workers' Alliance 2012);. Back injuries, slips and falls, and motor vehicle-related accidents are frequent with warehouse workers (Harrington 2006).
Occupational conditions for farm workers are often minimally regulated (Graham *et al.* 2008). Migrant workers are disproportionately affected because they tend to be given more manual, strenuous and repetitive tasks, required to perform intense physical labour (Arcury and Quandt 2007; Anthony *et al.* 2008), and put in situations with hazardous equipment (knives, machetes, etc.) with little safety training or supervision (Cole 2006). Language, cultural, and legal barriers also may impede them from seeking medical attention, which may lead to more protracted injuries (Otero and Preibisch 2010).

4.7.2 Environmental contamination

Air and water pollution caused by agricultural and food processing activities are the main pathways for the food system to cause negative human health impacts. Anthropogenic inputs such as fertilizers, pesticides, and chemicals, along with waste products from agricultural and industrial activities – including wastewater, irrigation runoff, manure and animal waste – leach into the environment and affect people's health (IPES-Food 2016).

Agriculture is the second leading cause of outdoor air pollution globally after emissions from residential energy use (Lelieveld *et al.* 2015). In many regions of the world agriculture is reported to be the largest contributor – with up to 40 per cent of air pollution in several European countries reported (ibid.). On a global scale, outdoor air pollution leads to 3.3 million premature deaths annually (ibid.). In particular, pollution with airborne particulate matter that is smaller than 2.5 micrometres in diameter (PM2.5) (Bauer *et al.* 2016) at high levels can cause acute lower respiratory illness, cerebrovascular disease, ischaemic heart disease, chronic obstructive pulmonary disease, and lung cancer (Lelieveld *et al.* 2015). Agricultural production is a key producer of PM2.5 matter. While air pollution affects all residents since airborne particulate matter may drift between regions and even from one country to another, it is at the intersection of intense agricultural production and large population centres (with concentrated industrial production and transport systems) that the chemical process of PM2.5 formation is most powerful. Indeed, in China, the 10 cities that registered the highest PM2.5 levels in 2013 were all surrounded by intensive agriculture (Gu *et al.* 2014).

Livestock production and fertilizer use are key culprits in air pollution, particularly, livestock production close to urban areas, which facilitates the mixing of SO_2 and NO_x emitted from fossil fuel combustion with agricultural NH_3, resulting in high levels of air pollution in cities (Gu *et al.* 2014; Paulot and Jacob 2014). Residents living near CAFOs are reported to have increased incidence of respiratory distress, digestive disorders, anxiety, depression, and sleep disorders. Children living on farms raising swine were reported to have a higher incidence of asthma, with increasing incidence as the size of the swine operation increased.

Policy changes to lower the maximum amount of permissive ammonia output may be instrumental in protecting public health from anthropogenic air pollution (Vieno *et al.* 2016). Long-term reductions in particulate matter in the atmosphere have been related to increased life expectancy (Pope *et al.* 2009). To achieve this, adjusting feed compositions for stock animals (to a diet with less protein, which leads to less excess nitrogen) and improving housing conditions for livestock operations also have emerged as key imperatives (Aldern 2015). Covering manure tanks, and using more careful application procedures of fertilizers, slurries, and manures can help decrease gaseous losses of nitrogen through ammonia emissions (Gu *et al.* 2014; Jokela *et al.* 2012).

Other forms of environmental pollution include persistent organic pollutants (POPs) such as dioxins and polychlorinated biphenyls (PCBs) have become widespread environmental contaminants (Fisher 1999). Their toxicity in humans and wildlife is enhanced by their persistence in the environment and their bioaccumulation potential through the food chain (ibid.). POPs include a variety of man-made chemicals including polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), PCBs, hexachlorobenzene (HCB), and several organochlorines used as pesticides whose use has been highlighted by international organizations as a health concern (Abelsohn *et al.* 2002; Grandjean *et al.* 2008). In addition to reproductive and developmental effects, many POPs are known or suspected carcinogens (Jones and de Voogt 1999; Ashraf 2017) and low-level exposure to some POPs has recently been associated with an increased risk of diabetes (Lee *et al.* 2006; Taylor *et al.* 2013).

Many significant health issues also have been associated with endocrine disrupting chemicals (EDCs), or endocrine disruptors (EDs), ubiquitous in our modern food systems due to pesticides used in conventionally grown crops as well as from hormones used in meat production, poultry, and dairy products. Chemicals used to coat food cans and in some plastic containers, compounds used as food preservatives, and even substances in non-stick cookware are all reported to be EDCs (Wielogorska *et al.* 2015). There are close to 800 chemicals known or suspected to function as EDCs (WHO and UNEP 2013).

EDCs in lab studies on in vitro cells have been associated with many female reproductive disorders, including cancers (Crain *et al.* 2008; Roy *et al.* 2009), urogenital tract malformation (Fernandez and Olea 2012), testicular cancer (Chia *et al.* 2010), and decreases in semen quality and sperm count (Li *et al.* 2011). Laboratory studies with animals also have associated EDCs with the development of diabetes and obesity (Newbold 2010; Thayer *et al.* 2012). The annual health costs of exposure to EDCs in the EU has been estimated at €163 billion/US$217 billion (a per capita cost of €428) (Trasande *et al.* 2016), while in the United States, the cost is estimated to be $340 billion, or 2.33 per cent of GDP (Attina *et al.* 2016) – see **Figure 4.4**.

The consequences of long-term exposure to pesticide residues in food are still poorly documented. This is particularly important in countries that have poor or no pesticide residue control measures in place (Lehmann *et al.* 2017). Yet it is also important in countries with stronger control measures. For example, a recent case in Europe of contamination of eggs by fipronil, a possible carcinogenic pesticide, has caused significant concerns (Boffey 2017; Food Standards Agency 2017). There is increasing need to address the potential risks of combined exposures to multiple residues from pesticides in the diet (Kortenkamp 2014). Emerging evidence shows that soil pollution and other types of environmental contamination pose appreciable health risks. Ammonia (NH_3) pollution from agriculture has been considered a major cause of health damage in the U.S. (Paulot and Jacob 2014).

Figure 4.4 Annual costs resulting from EDC exposure (Source: adapted from Attina *et al.* 2016; Trasande *et al.* 2016)

ANNUAL COSTS RESULTING FROM EDC EXPOSURE

$217 BILLION	**$340 BILLION**	**$42 BILLION**
EU - 1.28% of GDP	USA - 2.33% of GDP	USA - Pesticides alone

Water pollution is another significant challenge to health in our current food system. Nitrate and phosphorus pollution due to excessive chemical fertilizer use and feedlot runoff leaches into the groundwater system, through rain and soil seepage, carrying with it nitrogen, phosphorus, other chemicals, as well as multiple disease-carrying pathogens, such as *E. coli* (Anderson and Sobsey 2006; Dan-Hassan *et al.* 2012), leading to contaminated environments. Low-income agricultural communities in developing countries without access to potable water are most vulnerable to water pollution related health impacts. However, even in developed countries, increasing levels of agrochemical and nitrate pollution in public water sources makes it difficult for suppliers of drinking water to provide water below the maximum concentration of nitrate mandated by law (Ward 2009; PAN - North America 2012; Espejo-Herrera *et al.* 2016; Iowa Environmental Council 2016). High levels of nitrate in drinking water have been associated with spontaneous abortions (Tabacova *et al.* 1998; Guillette and Edwards 2005; Espejo-Herrera *et al.* 2016), birth defects including congenital anomalies, neural tube defects, methemoglobinemia, or blue-baby syndrome, a potentially life-threatening condition that decreases the blood's ability to distribute oxygen in the body (Gupta *et al.* 2008), and several types of cancer such as bladder cancer, thyroid cancer, and non-Hodgkin's lymphoma (Iowa Environmental Council 2016; Nolan *et al.* 2002).

The use of wastewater for irrigation in China, particularly in regions with concentrated mining and smelting activities, has resulted in dangerous levels of heavy metals in water sources and soils, while intensive of livestock production has led to increased concentrations of, zinc, arsenic and copper (Lu *et al.* 2015).The convergence of industrial activities and wastewater irrigation also has caused heavy metal pollution in other parts of the world (Luengo-Fernandez *et al.* 2013).

4.7.3 Pathogenic contamination

Another key element of environmental contamination from livestock concerns the spread of bacteria (including those with developed resistance to antimicrobials), e.g. bacteria from animal feces used as a fertilizer and remaining on crops, wind-blown transmission of dust from livestock operations, and bacteria from animal feces that enters into the water system (Centers for Disease Control and Prevention 2013; McEachran *et al.* 2015).

The threat of zoonoses – communicable human diseases originating in or carried by animal populations – is of concern relative to existing and emerging pathogenic risks (Newell *et al.* 2010; Slingenbergh *et al.* 2004; WHO 2013). Indeed, 75 per cent of emerging diseases and 63 per cent of current pathogen species are zoonotic in origin (Jones *et al.* 2013). New zoonotic infectious diseases emerge most frequently in areas where the natural habitat and wild animal populations overlap with the human habitats and landscapes devoted to domesticated animals (Leibler *et al.* 2009; Patz *et al.* 2004). Different forms of animal farming expose workers to different zoonotic diseases. For example, animal handlers working with dairy cows and sheep are at high risk from *Brucellosis* in endemic areas of Central Asia, Africa, and Latin America (Corbel *et al.* 2006), while herders in Africa are at higher risk from Rift Valley Fever (Anyangu *et al.* 2010).

Intensified, large-scale production and processing of livestock such as pigs and chicken have seen rapid increases in scale globally – particularly in low- and middle-income countries with relatively weak veterinary and public health infrastructure (Graham *et al.* 2008; Liverani *et al.* 2014). Combined with the pressures of urbanisation, the growing demand for animal products exacerbates competition for land and resources. Humans and domestic animals are more exposed to wildlife and the diseases they carry as food production encroaches onto wild ecosystems, often via deforestation, (Morse 2004; Patz *et al.* 2004; Goodwin *et al.* 2012).

Adverse health impacts from intensified production practices have been attributed in particular to industrial animal production facilities, such as feedlots and CAFOs where intensive production practices create a large number of interconnected amplification pathways for viral, bacterial, and parasitic pathogens. Livestock intensification allows for the introduction of pathogens into concentrated production units, where these disease agents adapt and reproduce at a rapid pace (Liverani *et al.* 2014; Slingenbergh *et al.* 2004). Workers also suffer microbial infections from working in processing plants. While the food-borne transmission route is the most common infection pathway in developed countries, Hale *et al.* (2012) show in the U.S. that up to 14 per cent of the enteric disease burden of seven major zoonotic pathogens can be attributed to direct animal contact.

In industrial livestock systems and fish farms, farmers frequently turn to antibiotics not only to treat sick animals, but also to prevent the outbreak of illnesses and accelerate the growth process of meat animals (Collignon *et al.* 2005). Globally, more antibiotics are used preventively in livestock operations than to treat human diseases (WHO 2012; CDC 2013; Ahmed and Shimamoto 2015; Laxminarayan *et al.* 2016; Spellberg *et al.* 2016). Many of the antibiotics used on animal agriculture and aquaculture are the same antibiotics as in human medicine (Cabello 2006; Done *et al.* 2015), leading to dangerous decreases in efficacy, since bacteria regularly exposed to an antibiotic can become resistant. The administration of low doses – common in preventative health or growth stimulation contexts – may kill most, but not all, bacteria in a particular population. Bacterial strains with minor mutations that remained unaffected by the antibiotic will then survive and reproduce rapidly, self-selecting for greater antibiotic resistance (Chang *et al.* 2015). Even production systems not using antibiotics directly can be vulnerable to contamination, such as through cross-use of manure. For example, a U.S. study found multidrug resistant (MDR) bacteria in all the samples of conventional retail chicken meat as well as in the majority of organic meat samples (Cohen Stuart *et al.* 2012). There is also the problem of antibiotic resistance that is transmitted directly from animals to their handlers, with many farm operators and workers having shown signs of antibiotic resistance (Price *et al.* 2007; Zhang *et al.* 2009; Meena *et al.* 2015;).

Fungal mycotoxins are another result of crop and food pathogenic contamination. These are secondary metabolites produced by fungi that colonize food crops (Wu *et al.* 2013)2013, mainly belonging to the *Aspergillus, Penicillium,* and *Fusarium* genera. Some 300 compounds have been recognized as mycotoxins, of which around 30 are considered a threat to human or animal health. Mycotoxin exposure via food and feed may result in carcinogenicity, immunotoxicity, reproductive toxicity, hepatotoxicity, nephrotoxicity, etc. (Bennett and Klich 2003). Global surveys indicate that more than 70 per cent of the samples of feed and feed raw materials tested are positive for at least one mycotoxin (Streit *et al.* 2013). Exposure to aflatoxin can lead to development one of the deadliest cancers worldwide – liver cancer. Aflatoxin is responsible for up to 172,000 liver cancer cases per year (Wu *et al.* 2013; Wu 2015;). Maize contaminated with aflatoxins has been implicated in deadly epidemics of acute aflatoxicosis in Kenya, India, and other countries (Lewis *et al.* 2005).

Individuals' health can also be compromised by the ingestion of contaminated foods. Food-borne disease agents fall into distinct categories – most importantly bacteria, viruses, and parasites – and can cause a variety of illnesses upon ingestion (Newell *et al.* 2010). Food containing harmful bacteria, viruses, parasites, or chemical substances cause more than 200 diseases, ranging from diarrhoea to cancer (WHO 2015b). While foodborne pathogens can cause severe diarrhoea or debilitating infections, food chemical contamination can lead to acute poisoning or long-term diseases, such as cancer. An estimated 600 million people – 1 in 12 people in the world – get ill from consuming contaminated food, and 420,000 die each year, resulting in the loss of 33 million disability-adjusted life years (DALYs) (WHO 2015b). Foodborne diseases impede socioeconomic development by straining healthcare systems as well as harming national economies, tourism, and trade.

The emergence of prions, infectious agents composed entirely of protein, such as the agent of bovine spongiform encephalopathy (the cause of variant Creutzfeldt-Jakob Disease in humans) has been associated with intensive animal production systems. Parasitical diseases such as cysticercosis, echinococcosis, and trichinellosis are related to traditional animal rearing methods, unregulated slaughtering, and consumption of animal products. Aquatic foodborne trematode infections affect more than 40 million people per year worldwide, over half in Southeast Asia and the Western Pacific (WHO Regional Office for the Western Pacific 2004). Research in the U.S. has attributed 46 per cent of foodborne illnesses recorded between 1998 and 2008 to produce infected by parasites, particularly *E. coli* and norovirus.

4.8 DIETARY PATTERNS AND FOOD INSUFFICIENCY

4.8.1 Dietary patterns

Besides impacts from exposure or contamination by pesticides, food additives, and hormones, dietary patterns of either over- or undernutrition can also negatively affect human health. Diets greatly influence risk factors for both chronic and acute disease, especially cardiovascular diseases, diabetes and some cancers. The leading metabolic risk factors for these diseases include overweight/obesity, hypertension, elevated blood glucose, and high cholesterol (WHO 2014a).

The worldwide prevalence of obesity more than doubled between 1980 and 2014. In 2014, more than 1.9 billion adults age 18 and older were overweight, of which over 600 million were obese. In 2014, an estimated 41 million children under the age of 5 were overweight or obese (Global Burden of Disease 2015 Mortality and Causes of Death Collaborators 2016; UN Children's Fund, WHO and World Bank 2017). The prevalence of overweight and obesity is rising in every region and nearly every country, including in both urban and rural areas in sub-Saharan Africa and in South Asia's poorest countries (Popkin *et al.* 2012). Among lower GDP countries, urban women are more likely than urban men to be overweight/ obese. The number of children younger than 5 who are overweight is approaching the number who suffer from wasting (IFPR 2016). The fetal origins hypothesis predicts that prenatal undernutrition could increase the propensity for obesity later in life (Barker and Osmond 1986; Adair and Prentice 2004; Almond and Currie 2011). Being overweight or obese increases the risk for cancers of the oesophagus (adenocarcinoma), colorectum, breast (postmenopausal), endometrium and kidney (Key *et al.* 2004; Reilly and Kelly 2011; Park *et al.* 2012). The problem of obesity is now a staggering and multi-dimensional global challenge.

Calories obtained from meat, oils, fats, sugars, and other refined carbohydrates have increased during past decades, and those from fibre-rich foods (whole grains, legumes, roots) have declined. The overall proportion of processed and highly processed food in diets has grown and is rising rapidly in low- and middle-income countries. In those countries, there has been a shift toward more Western diets, with increased reliance upon processed foods and greater use of edible oils and sugar-sweetened beverages (Popkin *et al.* 2012). Dietary patterns also are changing toward the consumption of more foods of animal origin. If trends continue, global demand for beef is projected to increase by 95 per cent, and animal-based foods in general by 80 per cent, between 2006 and 2050 (Ranganathan *et al.* 2016). These changes in dietary patterns – coupled with globalization, urbanisation, changes in lifestyle, and low physical activity – have been termed the "nutrition transition" (Wessels and Brown 2012). Such changes can lead to rapid increases in obesity and chronic diseases, even among the poor in developing countries (Popkin *et al.* 2012).

This is problematic for a number of reasons. First, fruits and vegetables have the potential to reduce calorie consumption through displacement of high-calorie processed foods. Furthermore, fruits and vegetables contribute to preventing cardiovascular disease and are protective against some cancers. Eating low-calorie foods (such as fruits and vegetables, which tend to be about 0.7-1.5 cal/g) in place of high-calorie foods (4-9 cal/g), appears to mitigate weight gain and help with its management (CDC 2005) in part due to the increased satiety of these lower calorie foods (Manitz *et al.* 2014) that have high volume and high water and fibre content (Popkin *et al.* 2012). Fruits and vegetables also contain a wide array of compounds that, although not nutrients in the classical sense, nonetheless may play an ancillary role in disease prevention and wellness. Cruciferous vegetables – including kale, collards, radishes, and broccoli – contain glucosinolates, a group of compounds thought to be cancer preventing (NIH 2012). Cooking and chewing them results in breakdown products such as indoles and isothiocyanates, which are felt to be chemopreventive in a variety of organs – for example, lung cancer (Rolls *et al.* 2004).

In general, the evidence to date are still mixed on the overall impact of increased fruit and vegetable consumption, at least in healthy populations, on cancer risk reduction (Key 2011). However, a new study from the Netherlands (Aune *et al.* 2017) indicates that consumption of 800 gm/d of fruits and vegetables (eight servings) reduces the risk of cardiovascular disease, cancer, and all causes of mortality. As the authors state, "an estimated 5.6 and 7.8 million premature deaths worldwide in 2013 may be attributable to a fruit and vegetable intake below 500 and 800 g/day, respectively, if the observed associations are causal."

Data from a large number of recent studies points to a reduction of red meat to help reduce the risk of cardiovascular disease (Willett 2012; Satija *et al.* 2017). Cured meat and red meat are likely to increase the risk for colorectal cancer, while preserved foods and high salt intake appear to increase the risk for stomach cancer (Key *et al.* 2004; Potter 2017). A 10 per cent increase in ultra-processed food intake has been associated with a 10 per cent increase of cancer risk (Fiolet *et al.* 2018). Chinese-style salted fish increases the risk for nasopharyngeal cancer, particularly if eaten during childhood.

Lifestyle factors, including diet, play an important role in the aetiology of cardiovascular disease (CVD). The most important behavioural risk factors for heart disease and stroke are unhealthy diet, physical inactivity, tobacco use, and harmful use of alcohol (WHO 2018a). The effects of behavioural risk factors may present in individuals as elevated blood pressure, elevated blood glucose, elevated blood lipids, and overweight/obesity. These, in turn, are indicative of an increased risk for heart attack, stroke, and heart failure.

Elevated weight (obesity/overweight) coupled with a lack of fitness is a major risk factor for NCDs such as cardiovascular diseases (mainly heart disease and stroke), diabetes, musculoskeletal disorders (especially osteoarthritis – a highly disabling degenerative disease of the joints), and some cancers (including endometrial, breast, ovarian, prostate, liver, gallbladder, kidney, and colon (WHO 2014a; WHO 2016b) through inadequate intake of fruits, vegetables, nuts, seeds, and dietary fibre, and high consumption of red and processed meat (Lim *et al.* 2012; Sabate and Soret 2014).

The relation between dietary patterns and human health is well established. Diets high in vegetables, fruits, whole grains, pulses, nuts, and seeds, with modest amounts of meat and dairy, promote health and well-being (Dietary Guidelines Advisory Committee 2015).

Generally, dietary recommendations across the globe include calls to increase the consumption of whole vs. refined grains. WHO (2015a) recommends whole grains as part of a healthy diet. The Whole Grains Council cites steady increases in the number of whole grain products available and the number of products re-formulated to increase the whole grain content (Aune *et al.* 2017). A meta-analysis demonstrated an inverse association between whole grain consumption globally, and type-2 diabetes risk (Aune *et al.* 2013).

Another consideration in our dietary patterns is the widespread introduction of ultra-processed foods. Ultra-processed products are ready-to-consume, entirely or mostly made from industrial ingredients and additives. They are typically energy-dense, have a high glycaemic load, are low in dietary fibre and micronutrients, and high in unhealthy types of dietary fat, free sugars, and sodium. Monteiro *et al.* (2013) have examined the growth in consumption of these products with a focus on Canada and Brazil, reporting a steady increase, such that ultra-processed products now comprise 54.9 and 26.1 per cent of total energy consumption, respectively (as of 2005) (see **Figure 4.5**). Across 79 high- and middle-income countries, the growth rate was highest from 1998-2012 among the lowest income countries studied, with growth rate slowing as per capita income increased. Monteiro *et al.* (2011) reported that increases in ultra-processed foods are largely at the expense of unprocessed foods and processed culinary ingredients, with an overall nutrient dietary profile that had more sugar, more fat, more sodium, less fibre, and higher energy density. A New Zealand study reported that, in supermarkets, the majority of processed foods were ultra-processed and had a far worse nutrient profile than culinary processed foods (Luiten *et al.* 2016). Baker and Friel (2016) examined food systems transformations in Asia and reported significant increases in ultra-processed foods – especially soft drinks.

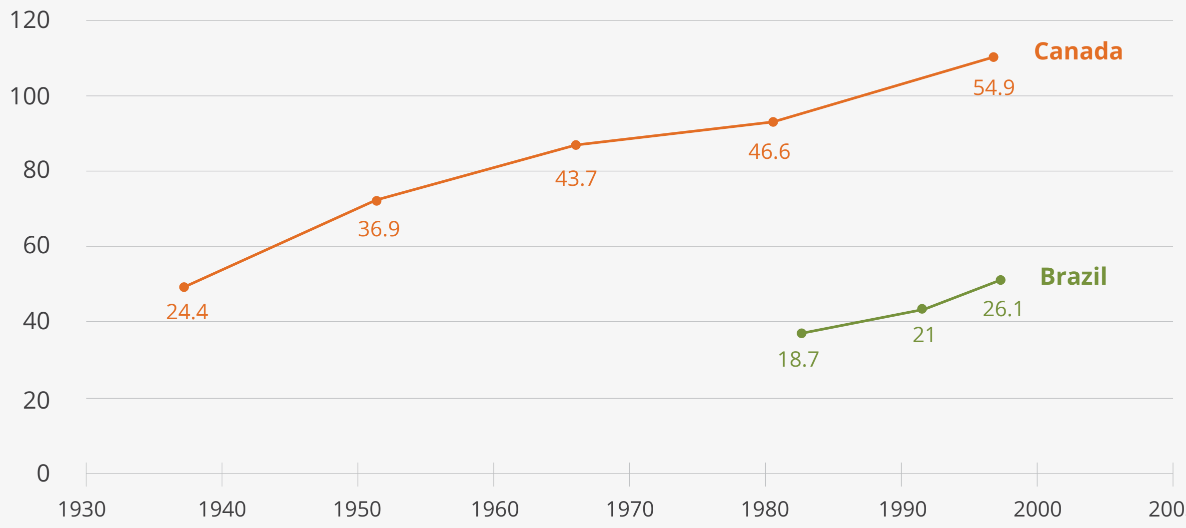
Diet is a central lifestyle component that plays an important role in the aetiology of cardiovascular disease (CVD). Other behavioural risk factors for heart disease and stroke are physical inactivity, tobacco use, and harmful use of alcohol (WHO 2018a). The effects may manifest in individuals as elevated blood pressure, elevated blood glucose, elevated blood lipids, and overweight/obesity. These, in turn, are indicative of an increased risk for heart attack, stroke, and heart failure.

Obesity results from a number of causes, including genetic background and endocrine disrupting chemicals widespread in our food supply (Gore *et al.* 2015). Yet, the most common proximate cause is an energy imbalance – the difference between calories consumed and calories expended (Wright and Aronne 2012). Changes in dietary and physical activity patterns are often the result of environmental and societal changes associated with development. Economic development across nations typically lacks supportive policies in sectors such as health, agriculture, transport, urban planning, environment, food processing, distribution, marketing, and education to minimize this caloric imbalance (Hawkes 2017). It has been hypothesized that continuous low-dose exposure to antibiotics in the meat supply, via gut biota modification, may influence obesity development (Riley *et al.* 2013).

Supermarkets and grocery stores are often the retail conduit for such foods and will play an increasingly important role in nutrition transitions. Access to technologies (e.g. processing, modern supermarkets, and food distribution and marketing), regulatory environments (e.g. the World Trade Organization [WTO]), and freer flow (e.g. of goods, services, and technologies) are contributing to and co-evolving with and often rapidly changing diets in low- and middle-income countries. Many groups focus on overall food supply, while the overall transition has shifted the structure of prices and food availability in significant ways.

The makeup of a diversified, balanced, and healthy diet will vary depending on individual needs (e.g. age, gender, lifestyle, degree of physical activity), cultural context, locally available foods, and dietary customs. Diets high in vegetables, fruits, whole grains, pulses, nuts, and seeds, with modest amounts of meat and dairy, have been shown to promote health and well-being (Dietary Guidelines Advisory Committee 2015). Basic principles of what constitutes a healthy diet according to the WHO are included in **Box 4.1**.

Figure 4.5 Time changes in the dietary share of ultra-processed products in the average household food basket in Canada and Brazil (Source: adapted from Monteiro *et al.* 2013)



Box 4.1 A healthy diet for adults (Source: WHO 2015a)

- Fruits, vegetables, legumes (e.g. lentils, beans), nuts, and whole grains (e.g. unprocessed maize, millet, oats, wheat, brown rice).
- At least 400 g (5 portions) of fruits and vegetables a day. This can save 2.7 million lives (WHO, 2008)
- Less than 10 per cent of total energy intake from free sugars, which is equivalent to 50 g (or around 12 level teaspoons) for a person of healthy body weight consuming approximately 2,000 calories per day, but ideally less than 5 per cent of total energy intake for additional health benefits.
- Less than 30 per cent of total energy intake from fats. Unsaturated fats (e.g. found in fish, avocado, nuts, sunflower, canola and olive oils) are preferable to saturated fats (e.g. found in fatty meat, butter, palm and coconut oil, cream, cheese, ghee, and lard). Industrial trans fats (found in processed food, fast food, snack food, fried food, frozen pizza, pies, cookies, margarines) are not part of a healthy diet.
- Less than 5 g of salt (equivalent to approximately 1 teaspoon) per day and use iodized salt.

FAO and WHO promoted the concept of Food-Based Dietary Guidelines (FBDG) following the 1992 International Conference on Nutrition. To date, only 83 countries (out of 215) have adopted dietary guidelines (Gonzalez Fischer and Garnett 2016). Dietary guidelines are particularly absent in low-income countries (e.g. only five countries in Africa have guidelines).

Several countries, such as the Nordic countries (Nordon 2014), Brazil (Ministry of Health of Brazil 2014), and the U.S. (Dietary Guidelines Advisory Committee 2015), have been providing evidence of the need to address sustainability in their FBDG. In general, the sustainable dietary guidance from these countries focuses on decreasing meat consumption, choosing seafood from non-threatened stocks, eating more plants and plant-based products, reducing energy intake, and reducing food waste. The Brazilian FBDG also address social and economic aspects of sustainability. The draft report of the U.S. FBDG at the time also addressed environmental sustainability and long-term food security – although environmental sustainability was eliminated in the final guidelines due to political pressure.

The social ecological model of behaviour indicates that the environment in which people exist plays a defining role in behaviour (Sallis *et al.* 2008; Golden and Earp 2012), and advertising is a key component of today's environment. Attempts to improve national dietary patterns often are confounded by advertising, selected sales, and product placements. Across the globe, such marketing contributes to negative health outcomes. In the U.S., an astounding amount of time and effort is spent encouraging children to request fast-food happy meals and other high-calorie foods (Federal Trade Comission 2008). The same is true across the developed world, such as England (Boseley 2016), Germany (Foodwatch 2015), and Australia (Watson *et al.* 2017). The WHO Regional Office for Europe (2017) has released data collection guidelines for the EU to help monitor meeting the goal of reduced advertising exposure of children. The same trends in junk food consumption are emerging in parts of Africa (Igumbor *et al.* 2012; Okoti 2017) and China (Dasgupta 2016) with alarming consequences for obesity rate increases. As indicated in a recent report, there is a strong correlation between the rate of commercial viewing and junk food consumption (Thomas *et al.* 2018). The ability of advertising to impact food choices – for better and for worse – should be included in any analysis of food system typology trade-offs.

Trade agreements can also strongly influence consumption changes. It is clear that one consequence of the North American Free Trade Agreement (NAFTA) is a big rise in obesity among Mexico's population, with a three-fold increase among women (ages 20-49) between 1988-2006 (Clark *et al.* 2012). In response, Mexico implemented a sugar tax on soft drinks with a demonstrated reduction in consumer purchases (Colchero *et al.* 2016). A WHO (2016c) report outlines a number of recommendations for greatly reducing childhood obesity , the sum total of which argues for much greater coherence between trade, agricultural, and health policy.

As stated earlier, traditional food systems have some highly processed foods (modern-to-traditional in the abbreviated typology used in this chapter), but the extent of their place in the market is far reduced relative to those with supermarkets as the end point (modern food system typology). This begs the question: when comparing food systems nationally or in a region, does it make sense to examine the manner in which the entire system begins to drive patterns of consumption, leading to changes in acute and chronic disease risk and then internalize those health and well-being costs? With a TEEBAgriFood Framework, this is not only desirable but also absolutely necessary to obtain a more complete picture of agricultural production and its overall implications for health.

4.8.2 Insufficient diets

In many countries the problem of obesity in some populations coexists with insufficient nutrient intakes among others. When it comes to undernutrition, the most prevalent concerns are overall calorie and/or protein deficits, vitamin A/beta-carotene deficiency, iron deficiency, iodine deficiency, and zinc deficiency. Globally, over two billion people suffer from some form of micronutrient malnutrition (IFPRI 2015). About 25 per cent of children globally are stunted, with the number rising to one-third in some developing countries (de Onis *et al.* 2012; Black *et al.* 2008). WHO 2018b) data from 2010 indicates:

- About 104 million children worldwide are underweight
- Undernutrition contributes to about one-third of all child deaths
- Stunting (an indicator of chronic undernutrition) hinders the development of 171 million children under age 5
- 13 million children are born prematurely or with low birth weight due to maternal undernutrition and other factors
- Together, maternal and child undernutrition account for more than 10 per cent of the global burden of disease.

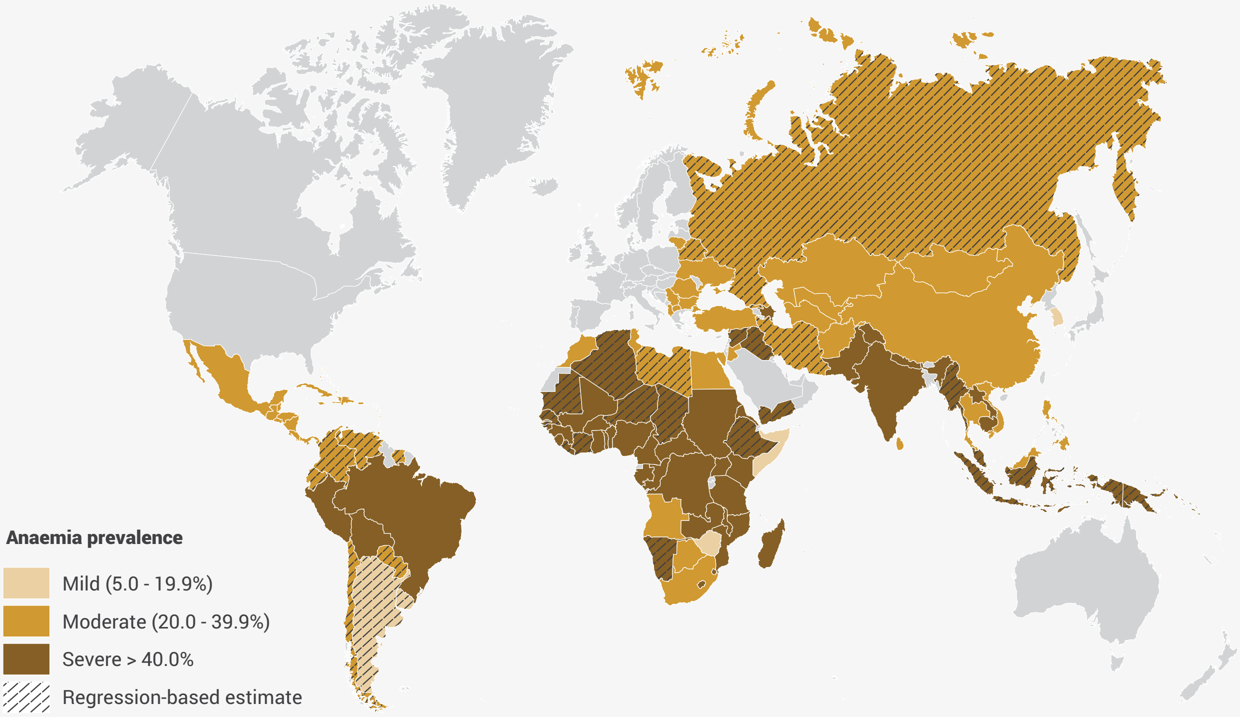
Vitamin A is an essential nutrient, key for proper vision, as well as immune system function. Humans obtain it either as vitamin A (from animal product sources) or in its precursor form – beta-carotene – of which many fruits and vegetables are excellent sources. Getting our daily need does not require a large amount of food. For example, two servings a day of carrots or spinach provides all the vitamin A required for everyone except lactating mothers (NIH 2016). Yet many people, especially young children, get well below their requirements because of a deficit of fruits, vegetables, and animal products in their diet. It is estimated that 190-250 million preschool children and 19 million pregnant/lactating women have sub-optimal intakes (WHO 2009; 2018d), resulting in an estimated 250-500,000 cases of preventable blindness per year. And yet this is, in theory, simple to resolve with or without staple crop bio-fortification.

Anaemia is another common micronutrient deficiency around the world (Stevens *et al.* 2013), affecting about 1.6 billion people globally, with much higher rates in the developing world (43 per cent) compared to the developed world (9 per cent) (McLean *et al.* 2009) It is particularly prevalent in high risk groups – children younger than 5 (see **Figure 4.6**) and pregnant/ lactating women – with 85 per cent of the total global prevalence among high-risk groups found in Africa and Asia. Overall, the greatest number of anaemia incidences is found in non-pregnant or lactating women – about 468 million (WHO 2008). Anaemia exhibits broad impacts in a community, including increased risk of infection, loss of productivity, cognitive impairment and difficulty learning. While many assume that anaemia is caused by iron deficiency, only about 50 per cent of global burden is due to levels of iron intake – although this number is a broad estimate (Ezzati *et al.* 2004). Three other micronutrients – folic acid, vitamin B12, and vitamin A (Zimmermann *et al.* 2006) – also play a role in erythropoiesis (red blood cell formation). Depending on the area of world and type of diet, these also are implicated for significant portions of the global burden. In addition, a number of parasites, especially hookworm (Bartsch *et al.* 2016) increase the risk of anaemia – via both enhanced blood loss and/or impacts on iron absorbability.

A number of factors affect iron absorption in the intestine: animal-based iron is more absorbable than plant-based (due to phytate binding); sufficient vitamin C increases absorbability of iron due to an intestinal effect; reduced parasitic infection increases iron absorption, among other factors. Vegetarians often have lower B_{12} levels (necessary for intestinal and red blood cell formation) than omnivores, largely dependent on the degree of vegetarianism and/or the consumption of other B_{12} containing foods, such as yeast products. In the case of anaemia and diet, having a healthy, balanced diet presents a much better individual profile for limiting the risk of anaemia and attendant deleterious effects. Five strategies can help reduce the incidence and burden of anaemia: access to diverse food sources, clean water and sanitation, fortified foods, health services, and knowledge and education.

Zinc is another element necessary for several health outcomes including normal pregnancy, lactation, neuromuscular development, gonadal development, and growth (Prasad 1991). Zinc deficiency is not as widespread as the lack of some other nutrients, yet it is still a major public health concern. **Figure 4.7** illustrates the estimated rates of zinc deficiency across the globe, determined by the prevalence of zinc in the national food supply. The authors estimate about 17 per cent of the global population is at risk for zinc deficiency, and there was a strong negative correlation between the total calories available in a country and the level of zinc deficiency – as calories available increased, zinc deficiency decreased. Like iron, zinc is more bioavailable from animal products than plant. That said, there are a number of good plant sources of zinc.

Figure 4.6 Global prevalence of anaemia in children of preschool age 0-5 years (Source: adapted from Balarajan *et al.* 2015)

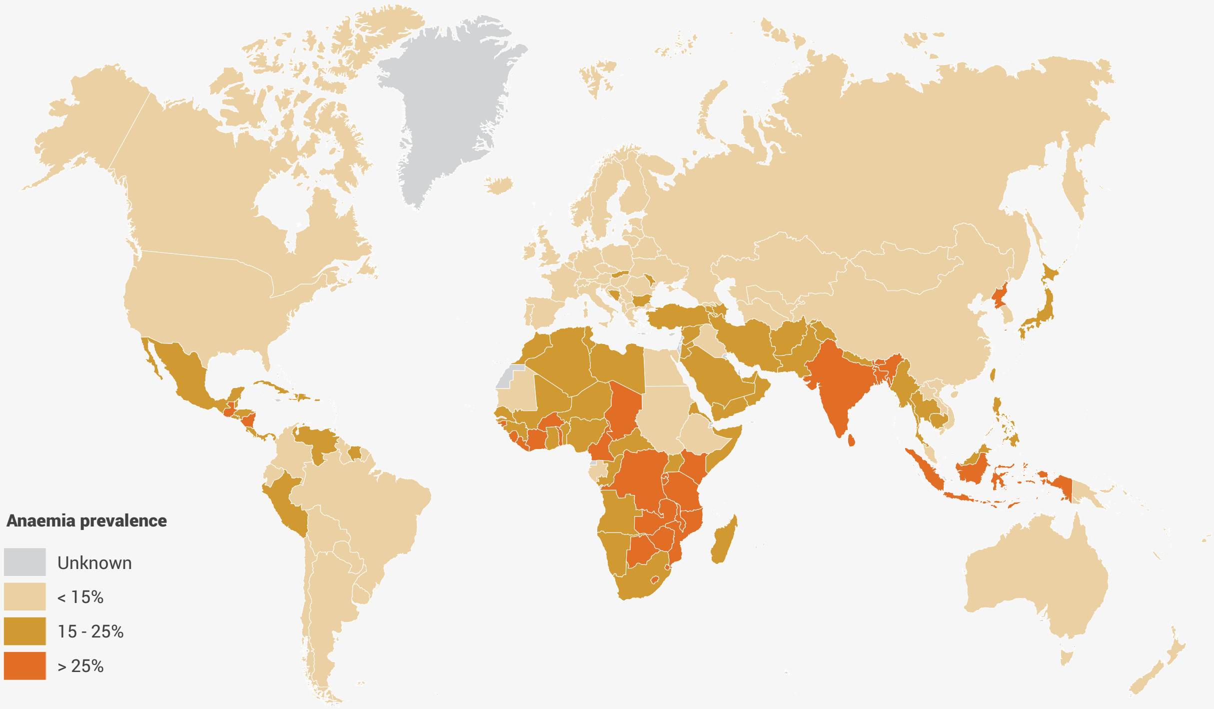


It is estimated that about two billion people globally have insufficient intakes of iodine (Zimmermann 2009), with sub-Saharan Africa and Asia particularly affected. Its primary function is the production of thyroid hormone (deficiency producing goitre as a physical/visible manifestation of frank deficiency, with cretinism the most extreme consequence in living offspring). Inadequate levels affect growth, development, and maturation. Iodine deficiency during pregnancy has adverse implications for infant mortality. Unfortunately, the iodine content of most foods is relatively low – with seafood (and seaweed) being a striking exception due to the concentration of iodine found in sea water. Generally, iodization of salt is the most efficient and best strategy for decreasing iodine deficiency (Zimmermann *et al.* 2008) since the level of iodine in plants/animals is very dependent on soil content levels (true for other minerals as well).

Earlier in this chapter, there is a good deal of discussion concerning the nutrition transition including high levels of animal product consumption. While this is a tremendous environmental (including climatic) and landscape burden, it should be noted that animal products are a great source of several micronutrients that show high rates of insufficient intake globally (e.g. iron, zinc, andvitamin B_{12}). However, far lower meat intakes than the U.S. pattern or even than the current global average are sufficient for a population to meet recommended levels. If, for example, everyone ate about the average of 42 kg/yr or 115 gm/day, then, on average, about 35-50 per cent of the protein requirement and a significant per cent of key micronutrient requirements would be met by meat (see McMichael *et al.* (2007)). Three things should be noted here: this is true in the context of a healthy diet – not instead of one. Also, this assumes the meat-ingesting population has a low or zero burden of parasites, such as hookworm and schistosomiasis. Ensuring human health in the context of food means an ample, diverse supply of fruits and vegetables, as well as whole grains and plant legumes. In combination, this provides a strikingly rich micronutrient intake.

Undernutrition at its extreme manifests as famine, an episodic event has the potential to become even more frequent and devastating due to enhanced environmental change compounded by conflict (or conflict compounded by environmental change). For example, in March 2017 the UN emergency relief coordinator warned of the worst famine since 1945 with 20 million lives at immediate risk in South Sudan – with climate change as the primary trigger compounded by war (Falk 2017). It is likely that famine will be more common moving forward as climate change and fresh water shortages both directly impact the food supply and potentially lead to more conflict.

Figure 4.7 Estimated country-specific prevalence of inadequate zinc intake (Source: adapted from Wessels and Brown 2012)



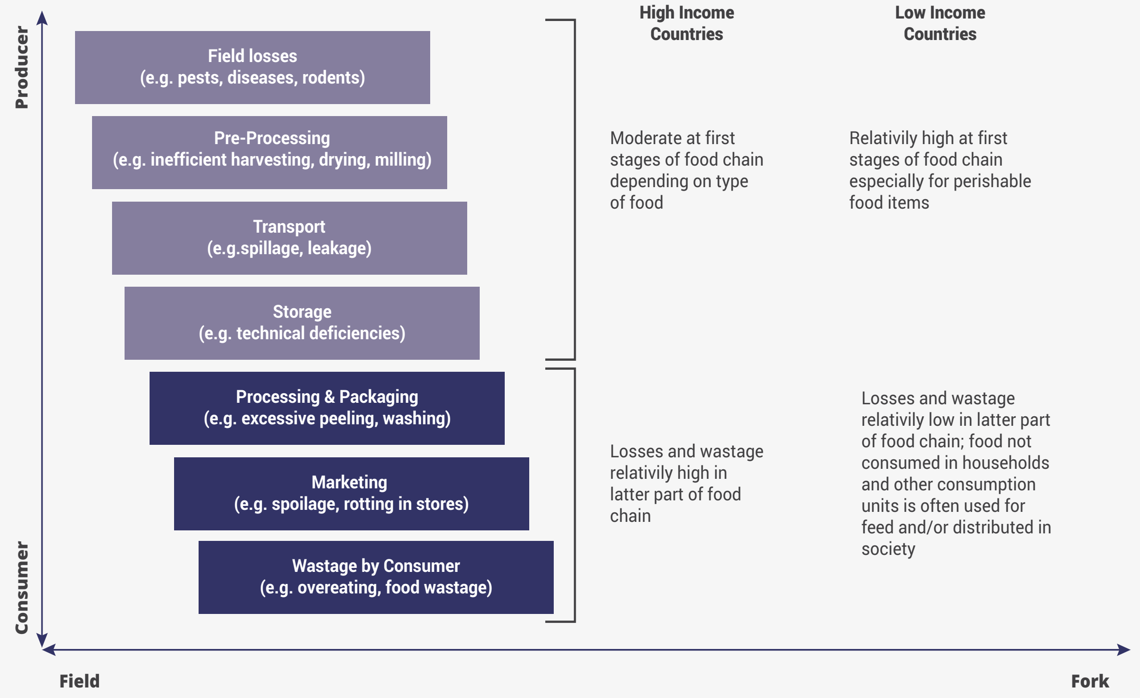
4.9 FOOD LOSS AND WASTAGE

Though it might sound trite, people cannot be healthy if they do not have food. Harvest and post-harvest management of crops and animal products is critical to ensuring food gets to people's mouths in as pristine a state as possible – without contamination (chemical or biological) and with minimal decline in nutritional quality. The loss of foodstuffs across the food supply chain is one of the more vexing problems for a variety of reasons. Food that is produced and never finds a human stomach – or an animal intermediary – has typically used land, water, fertilizer (and/or compost), mechanical farm implements (often), and human labour in its production, yet it never satisfies anyone's hunger, needs, or wants. Food that is produced and never consumed also means that more land and resources will need to be used to fuel a growing global population, since what is currently produced is inefficiently captured in and along the supply chain.

While estimates vary, it is generally considered that somewhere between 30-50 per cent of all food that is produced is wasted (Fox and Fimeche 2013), with FAO (2011) estimating about 1.3 billion pounds of food wasted per year. How much of what is lost varies greatly across regions. As illustrated in **Figure 4.8**, these losses occur at a number of stages. Developed countries have relatively few losses in the early stage of the food system supply chain, but a great deal of wastage by consumers. Conversely, developing countries have high losses in the early stages and relatively low losses later.

However, this is not absolute. The developed world has much to improve in terms of strategies around consumer perception and perceived marketability. For example, a study of the Swiss potato supply chain indicates there is about a 53 per cent loss along the chain, with 40 per cent of that loss due to consumer preference (Willersinn *et al.* 2017). In the U.S., it has been estimated that approximately $166 billion dollars of fresh food is lost each year, most of it as consumer wastage – 41 per cent of meat, fish, and poultry, 17 per cent of vegetables, and 14 per cent of dairy – about 124 kgs per capita (2008 data) (Buzby and Hyman 2012). There is a large greenhouse gas (Heller and Keoleian 2015) and water footprint cost to this loss and waste.

Figure 4.8 Main types of food losses and wastage (Source: adapted from Lundqvist 2008)



Beyond consumer wastage in the home, there is much that can be done. Enhancing urban food security for a burgeoning urban population necessitates doing more – food-preserving harvest and food chains will be even more important going forward than they are now, with lower rural and higher urban populations. In a TEEBAgriFood Framework, identifying food system typologies that afford the best blend of health and environmental sustainability implies insuring significant reductions in food waste.

In the developed world, much of this food loss could be used to reduce imports and preserve land in other countries for domestic consumption – with implications for biodiversity conservation as well (Lenzen *et al.* 2012). So what would it take to reduce food losses and wastage in the developing world? A large percentage of losses occur at the farm – either through field losses and/or incomplete harvest due to poor equipment, lack of labour, and/or lack of perceived/actual markets. Crop losses also occur due to and to inappropriate storage, where better technology could decrease post-harvest losses early in the supply chain.

4.10 SUPPLY CHAINS, ACCESS, AND AVAILABILITY: THE TEEBAGRIFOOD FRAMEWORK AND FOOD SECURITY

Farmers need robust markets, and population growth and urbanization affect market trends. Supermarkets have increased in number dramatically worldwide (Reardon *et al.* 2003; Weatherspoon and Reardon 2003; Traill 2006), raising a number of questions about their role in improving heath status and food security. Do supermarkets provide a healthier package of food options than traditional markets? Are supermarkets accessible to the most food vulnerable? Do supermarkets provide a greater range and number of livelihoods across a spectrum that feeds back on improving health and food security? Do supermarkets provide a good strategy for traditional farmers to enter the market or do they skew the production framework? These questions can have very different answers in different parts of the world, with a number of confounding factors. Each of the food system types described by Gomez and Ricketts (2013) have strengths and weaknesses relative to food security and healthy diets. **Figure 4.9** shows that, in a sample of developing countries, traditional markets provide a large percentage of the fruit and vegetable market, but they tend to be more seasonal in nature. This will tend to have a positive impact on consumption of many micronutrients, at least while in-season.

In addition, traditional markets tend to provide more livelihood opportunities in the value chain for fresh product. Can modifications increase year-round availability? Is this useful?

Modern-to-traditional markets are able to move more processed goods into traditional markets at relatively low cost, thus providing greater options for consumers at these markets and providing a greater diversity of products for lower-income buyers. These points of sale also have the potential to move fortified foods (e.g. iodized salt; B-carotene enriched oils) into populations. However, low-nutrient foods/beverages (think carbonated soft drinks) are also more readily available, contributing to the rising rate of obesity and diabetes in the developing world. The traditional-to-modern trend is typically defined as smaller and more local producers marketing through modern outlets, like supermarkets. This has the potential of increasing market opportunities and providing more income for growers. However, such opportunities may only be available to somewhat larger, more educated, and more refined producers able to meet quality standards.

Overall, using a food system perspective looking to optimize health, food security, environmental sustainability, and social equity, the picture is very complicated. For example, in **Figure 4.10** and **Figure 4.11**, Tschirley *et al.*(2014) analyzed the potential purchasing habits of consumers in East and Southern Africa in 2010 and projected for 2040. In 2010, about 40 per cent of a household's food supply was self-generated – partially reflecting the rural nature of the majority population. By 2040, this is projected to decline to 31 per cent (reflecting continuing urbanization). Importantly in 2010 the overall market (that is food purchased outside the home as opposed to food grown for their own consumption) was about 85-95 per cent composed of the traditional market sector, and this will only decline to 60-70 per cent of the total market sector by 2040 (with a concurrent slight rise in supermarket buying). Interpolating from this, it is probably true this will be an even higher per cent for the lowest economic strata. In other words, food security will not be possible without a strengthening of the traditional market sector via public policy and infrastructure (e.g. potable water, security, and others) (White *et al.* 2016) and appropriate technology (e.g. scaled, renewable energy-driven cold storage) at a minimum.

Figure 4.9 Fresh fruit and vegetable market share of modern and traditional market retail sales (Source: adapted from Gomez and Ricketts 2013)

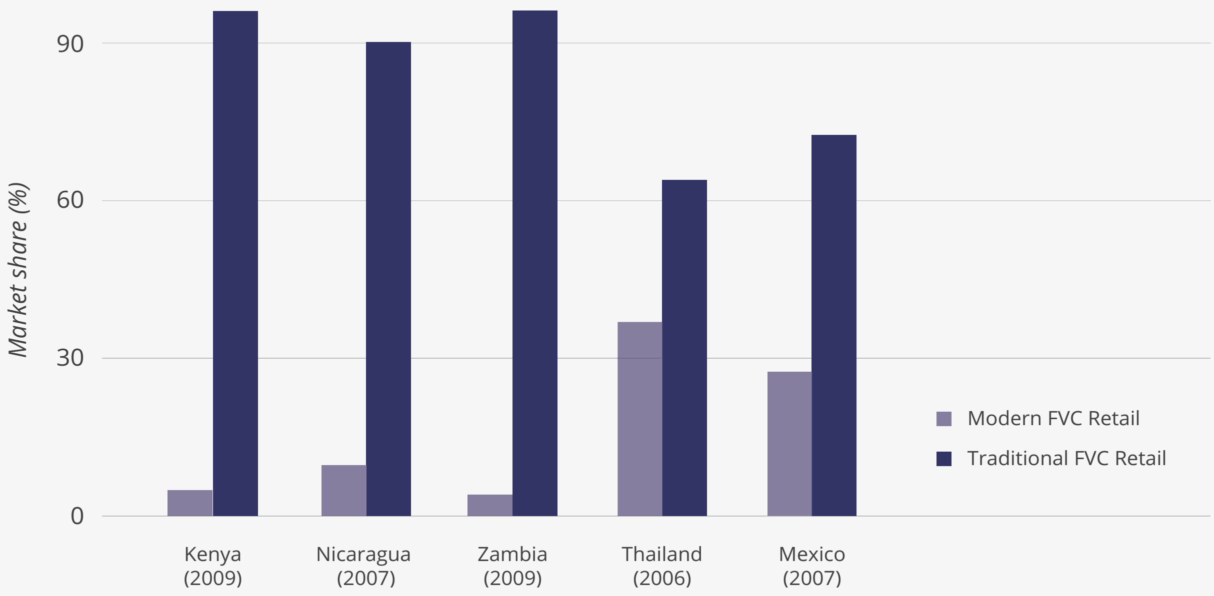


Figure 4.10 Structure of food marketing system in East and Southern Africa in 2010 (Source: adapted fromTschirley *et al.* 2014)

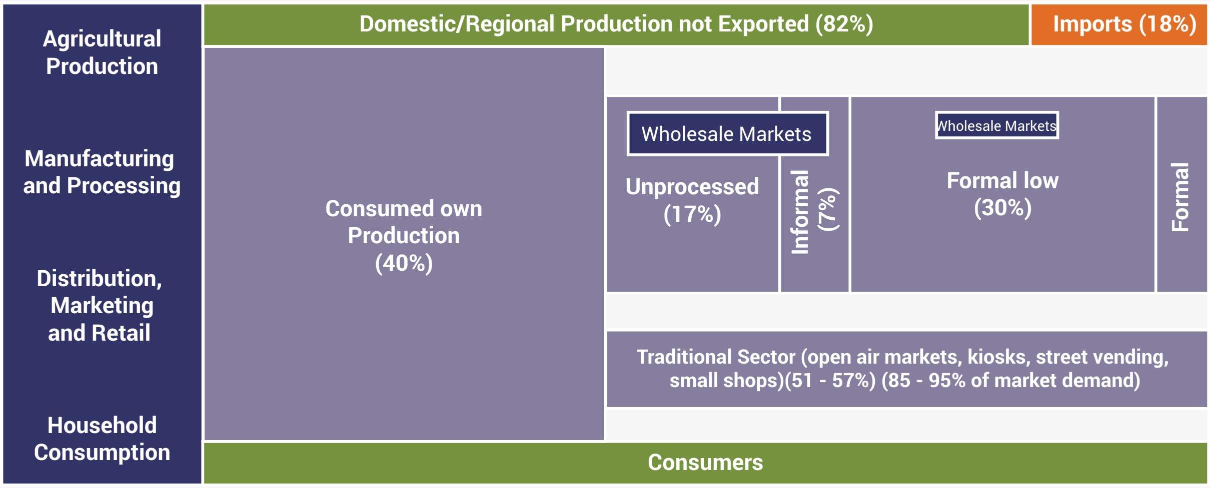
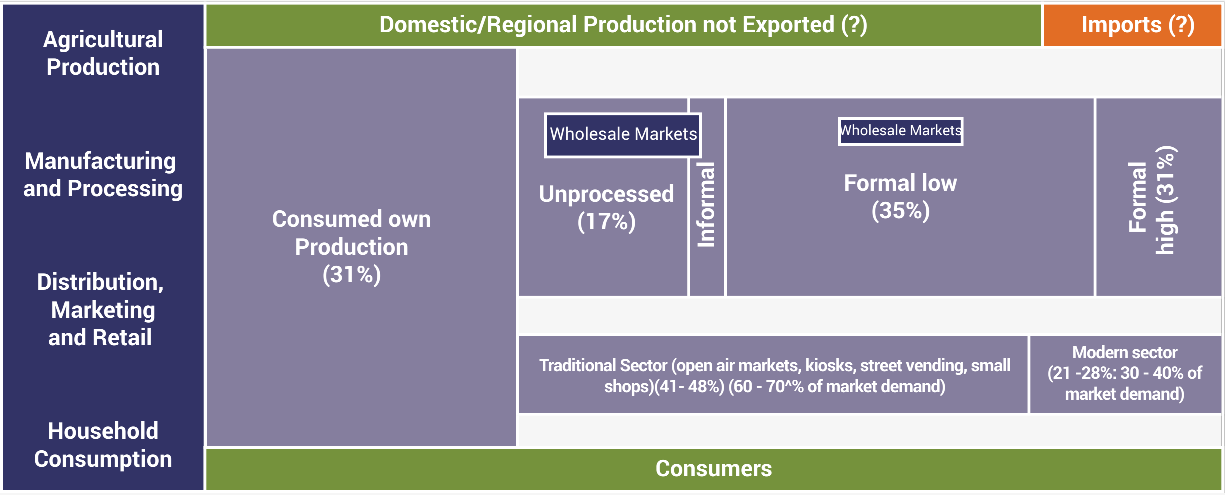


Figure 4.11 Projected structure of food marketing system in East and Southern Africa in 2004 (Source: adapted from Tschirley *et al.* 2014)



As Tschirley *et al.* (2014) identify in their modelling, the food purchasing power of the future will be very dependent on the types of economic growth trajectories implemented by governments – one that explicitly aims to spread the benefits across the economic strata will offer better purchasing power across society (i.e. greater opportunity for broad food and nutrition security). Battersby *et al.* (2016) found that those who are least food secure in South Africa tend to shop more often and for more goods in informal, traditional markets than in the emerged supermarket sector. All of these findings, while requiring further research, indicate that the supply chain endpoint and the supply chain itself can have an impact on food security for the most vulnerable. Using the approach outlined in this report provides an opportunity to evaluate not just the economics of the endpoint of food but also to enhance food security for the most vulnerable populations, by taking stock of a wide range of sustainable livelihoods along the supply chain and illuminating the trade-offs of different types of food system supply chains.

4.11 OTHER ISSUES AFFECTING HUMAN HEALTH AND NUTRITION (CLIMATE CHANGE, LIVELIHOODS, FRESH WATER IN CONTEXT OF SDGS)

Foods differ substantially in the quantity of land, water, and energy needed per unit of energy, protein or micronutrients supplied. They also differ substantially in the amount of GHG emissions generated. Predictive studies show that, if global diets change in an income-dependent way (i.e. following the trend that people with a higher income consume more animal protein), global-average per capita dietary GHG emissions from crop and livestock production would increase 32 per cent from 2009 to 2050 (Tilman and Clark 2014). It is estimated that alternative balanced or healthier diets such as Mediterranean-type, pescetarian, and vegetarian diets could reduce emissions from food production below those of the projected 2050 income-dependent diet, with per capita reductions being 30 per cent, 45 per cent, and 55 per cent respectively ibid.).

Increasing global trends in meat consumption are expected to increase the GHG emissions related to food between 30-80 per cent by 2050 and can have profound long-term impacts on the availability and pricing of certain basic food commodities and access to nutritionally diverse food sources (Friel *et al.* 2009). This presents a set of complex challenges for environmental sustainability and climate change mitigation. The food system requires a shift towards much greater environmental sustainability but global food and nutrition dietary patterns continuing on their current trajectory would add to greater environmental stress in the coming decades.

Climate change affects environmental determinants of health – clean air, safe drinking water, sufficient food, and secure shelter. We cannot achieve SDG 2 (zero hunger) without addressing SDG 13 (climate action). Climate change and climate-related disasters also exacerbate many socio-economic factors and social determinants of health, such as insufficient access to education, information, and resources or ability to work; and they threaten the functioning of institutions critical for human health and well-being, including public health services and social protection systems. This undermines climate resilience and the climate adaptation capacity of vulnerable populations.

Climate change effects on water, sanitation, and energy availability have major implications for food access and utilization (Porter *et al.* 2014) and may affect undernutrition and health outcomes (Smith *et al.* 2014). It has been conservatively estimated that, between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year from malnutrition, malaria, diarrhoea, and heat stress (WHO 2014a). The global food price rise in 2010-12 may have in part been related to climate change and if so is likely to have had a significant and adverse effect on human health (Butler 2014). More negative outcomes are expected if trends continue. Compared with a future without climate change, the following additional deaths are projected for the year 2030: 38,000 due to heat exposure in elderly people, 48,000 due to diarrhoea, 60,000 due to malaria, and 95,000 due to childhood undernutrition ibid.).

Populations in water-scarce regions are likely to face decreased water availability, particularly in the sub-tropics, with implications for the consumption of safe food and drinking water. In other areas, flooding and increased precipitation are likely to contribute to increased incidence of infectious and diarrhoeal diseases.

Most of the projected climate-related disease burden will result from increases in diarrhoeal diseases and malnutrition. Diarrhoeal diseases particularly affect nutrient absorption and food utilization. Climate change is projected to increase the burden of diarrhoeal diseases in low-income regions by approximately 2-5 per cent in 2020 and will impact low-income populations already experiencing a large burden of disease (WHO 2014a). Climate change plays an important role in the spatial and temporal distribution of vector-borne diseases such as malaria, which further affects food utilization, by increasing metabolic rate and caloric demand.

Climate change and variability can also impact the occurrence of food safety hazards at various stages of the food chain, from primary production to consumption (Tirado *et al.* 2010). Temperature increases and changes in rainfall patterns have an impact on the persistence and patterns of occurrence of bacteria, viruses, parasites, and toxigenic fungi, and the patterns of their corresponding foodborne (many diarrhoeal) diseases and nutrition (ibid.).

According to the IPCC (2014), if current climate change trends continue, there is 'high confidence' for increased risk of undernutrition in poor regions. According to Nelson *et al.* (2009), calorie availability in 2050 is likely to decline throughout the developing world, resulting in an additional 24 million undernourished children – 21 per cent more than in a world with no climate change, almost half of whom would be living in sub-Saharan Africa . Furthermore, Lloyd *et al.* (2011) projected that climate change will lead to a relative increase in moderate stunting of 1 per cent to 29 per cent in 2050, compared with a future without climate change. The same study reported that climate change will have a greater impact on rates of severe stunting, which are estimated to increase in the range of 23 per cent (in central sub-Saharan Africa) to 62 per cent (in South Asia).

Springmann *et al.* (2016) also predict that climate change could cut the projected improvement in food availability by about a third by 2050 and lead to average per-person reductions in food availability. If these changes occur it could contribute to an additional 529,000 climate-related deaths worldwide by 2050. The largest number of these climate related deaths are projected to occur in Southeast Asia and the Western Pacific Even as climate change makes food less available overall, it also has the potential to negatively impact the nutritional quality of food that is grown. A recent study highlights the potential for decreased protein content of staple crops due to increased atmospheric CO_2 (Medek *et al.* 2017; Myers *et al.* 2017) and builds on the earlier work of Loladze (2014) who also demonstrated decreases for a number of minerals including iron, zinc, and copper.

The IPCC (2014) highlighted the opportunities to achieve co-benefits from actions that reduce emissions and at the same time improve health by shifting consumption away from animal products – especially from ruminant sources – in high-meat consumption societies, toward less emission-intensive healthy diets (Smith *et al.* 2014). Sustainable and healthy diets can improve public health and nutritional outcomes while contributing to the reduction in GHG emissions and climate change mitigation goals (Friel *et al.* 2009; Tilman and Clark 2014; Green *et al.* 2015; Springmann *et al.* 2016). A general transition to more nutritious and diverse diets (with fewer processed foods and more fruits and vegetables) is likely to have a side effect of reduced GHG emissions as well as likely reductions in non-communicable diseases (Green *et al.* 2015; Milner *et al.* 2015). In other words, climate and food security are intimately connected. Dietary patterns can either play a role in mitigating the extent of climate change while insuring global food security *or* exacerbate the negative effectors for global food security. The TEEBAgriFood Framework can be used to determine best food system strategies for positive outcomes across all these areas.

Achieving SDG 6 (clean water and sanitation) presents a unique challenge for humanity and human health as we negotiate the 21st century. **Fresh water** is used in every facet of our society, and it is indispensible to human (and other) life. In a food system context, we use it for production, processing (including cleaning and canning), preparation, and waste handling. We have a seemingly insatiable ability to abuse water supplies across the globe and, similar to fossil fuels, we are mining ground water at our peril. We cannot substitute water for some other molecule.

Each person needs about 3-6 litres of water per day for direct water consumption to maintain health and hydration (this is for a 70 kg human). This two-fold variation depends on climate and physiological factors – 3L in more temperate environments and up to 6L in more tropical climates (Grandjean 2004). About 1.1 billion people have inadequate access to water in developing countries, and almost two-thirds of people lacking clean water access live on less than $2/day (Watkins 2006). Many people, mostly women, spend large amounts of time collecting water each day. Beyond the direct water intake required daily, we also all need water for cooking. Combined water requirements for cooking and drinking amount to about 5.5-9L/day or 2000-3300L/year (Reed and Reed 2013). This does not include water for other domestic uses. Our most precious nutrient is far from an assured resource for most of the world's population.

Our current use of water also has implications for our future food productivity. Globally, there are about 301 million hectares of irrigated cropland – 38 per cent utilizing groundwater – with the largest acreages in India, China, and the U.S. (Siebert *et al.* 2010). If current trends continue, much of this water will be mined out over the course of this century. For example, the 451,000 km^2 High Plains Aquifer in the U.S. underlays ground that produces nearly 20 per cent of U.S. wheat, corn and beef on 5.7 million hectares (USDA 2013). It is estimated that 35 per cent of the Southern High Plains will be unable to support irrigation in the next 35 years (Scanlon *et al.* 2012). Recent estimates indicate that without major improvements in water usage and preservation, a large swath from Africa through Asia will be critically short of water in the not-too-distant future (World Bank 2016). This provides another compelling reason to slow population growth in the context of human rights, gender equity, education and health care.

Climate change and freshwater access will undoubtedly impact the ability of millions to billions of people to maintain or enhance **livelihoods** and hence their ability to achieve SDG 8 (decent work and economic development). Globally, vast numbers of people are engaged in food system-related jobs and livelihoods, the majority of which are within the informal economy given the overall proportion of informal jobs across 45 countries surveyed (ILO 2013). The supply chain from rural farms to markets in many countries involves a broad array of jobs – traders, wholesalers, transportation workers, small-scale food processors, caterers, and vendors. One aspect of the informal economy relative to the food system is street food, i.e. food prepared for immediate consumption. FAO estimates that about 2.5 billion people globally eat street food daily, often accounting for a significant per cent of daily food expenditures and nutritional intake (Fellows and Hilmi 2011). It is estimated that 45 per cent of all slaughtered livestock passes through the informal economy (Aliber 2009) while the informal sector buys a significant percentage (29 per cent) of the total potatoes in the food system (Du Preez 2011). Even-Zahav and Kelly (2016) did a systematic review of the literature on the informal food economy and food security for South Africa. For many poor South Africans, the informal food sector is critical for any semblance of food security.

It is estimated that there are at least 570 million farms (Lowder *et al.* 2014) distributed across the 4.9 billion hectares of global agricultural land. The majority of these farms are under 1 hectare. They account for around 1 billion people working in the agricultural sector (FAO 2012), representing one-third of all workers. Although it is very difficult to determine with reasonable certainty the extent of the informal and traditional markets/supply chains for food across the globe, several things are clear:

- The number of people making a livelihood in the informal and traditional market sectors across the developing world is large – in the billions, when smallholder farmers are included.
- This part/type of food system has been understudied and underserviced given the critical role it plays in both livelihood development and food security.
- This part/type of food system probably becomes more – and not less – critical as urbanization continues across the developing world.
- There are a number of steps that could be taken to enhance the opportunities and options for people building informal small businesses within this food system.
- The TEEBAgriFood Framework provides a good strategy for understanding differential livelihood impacts of different food system development patterns.

4.12 CONCLUSION AND MOVING FORWARD

In this chapter, we provided a broad look at the relationship between our food system both globally and locally and the promotion of human health. We described a suite of challenges across the food system – for both those whose livelihood is based in the food system and for all of us who eat. The TEEBAgriFood Framework provides an architecture for analyzing different food pathways and for identifying business strategies, government and institutional policies to strengthen food systems and community norms of behaviour. This, in turn, provides a structure for engaging across the food system in the context of today's – and tomorrow's – challenges. Finally, it appears obvious that meeting the 17 Sustainable Development Goals and many of the associated 169 targets necessitates a large-scale effort to rethink, restructure, and rebuild our global food system.

How does the context of urbanisation, population growth, fresh water, environmental degradation, climate change, and livelihood enhancement relate to the type of food system best suited to satisfy the need for universal food security and healthy food patterns? In broad brushstrokes, on one side is an extremely globalized food system ("modernized," in the typology used in this chapter) in which supply chains are fed by lowest cost, transportation, and cold chain (when necessary) infrastructure that are state of the art, and outlets predominantly via supermarkets of various types. In this scenario, the key is international trade on a much larger scale than currently experienced. While an amount of global trade is both good and necessary, as it scales ever larger, it has can also have a variety of negative consequences. For example, it is clear that NAFTA has helped drive an obesity epidemic in Mexico (Clark *et al.* 2012). Research has shown international trade can drive threats to biodiversity in developing nations (Lenzen *et al.* 2012). Also, there are attendant risks to supply chain disruptions and consequential impacts to local food security. High input, industrial type production systems that typically supply globalized food systems are, for the most part, environmentally unsustainable and substantially contribute to the negative health impacts described in this chapter (IPES-Food 2016). Maximizing production through expanded acreage also can drive unsustainable outcomes such as soil loss – for example, large amounts of U.S. soybeans (in 2014-15 about 45 per cent)(Newton and Kuethe 2015) and corn/corn products from the Mississippi Basin are exported annually USDA 2014). Relatively small changes in production, i.e. taking most sensitive lands out of production and restoring perennial prairies, could have outsized impacts on nutrient and soil retention (Liebman *et al.* 2013). Transportation systems are being challenged with choke points, infrastructure weaknesses, and potential environmental impacts yielding a great deal of disruption potential (Bailey and Wellesley 2017).

On the other hand is the notion of more regional/local food systems ("traditional" in the typology used herein). These will not *a priori* ensure fair labour practices, environmental sustainability, or food security and human health (Bellows and Hamm 2001), butthey do have the advantage of bringing the benefits and impacts in closer proximity to one another – and in closer proximity to the end users. While this can hopefully enable greater transparency it does not guarantee that consumers are cognizant of production and labour practices. For example, while consumers perceive that food safety, production practices, and food quality are enhanced at U.S. farmers markets (Wolf, Spittler and Ahern 2005; Yu *et al.*, 2017) the reality is that the production practices of these farmers is pretty consistent with the general population of farmers (Low *et al.* 2015).

Hamm (2008a; 2008b; 2009) argues that a blend of regional ("traditional") and global ("modern") is what is needed – with regional being maximized to the extent that is regionally feasible across the globe. In much of the developing world, we are seeing the challenges of maintaining and improving these traditional food systems in the face of modernization, while many in the developed world are trying to rebuild these food systems within a "modern" system that has destroyed much of what had been "local".

Throughout this chapter, illustrations of challenges and opportunities in the food system as it exists have been highlighted with respect to health. Nutrition-sensitive, sustainable food systems are fundamental to reducing undernutrition and improving nutrition security in a changing climate (Tirado *et al.* 2013). A sustainable food system would deliver food and nutrition security for all in such a way that the economic, social, and environmental basis to generate food and nutrition security for future generations are not compromised (HLPE 2014). It would nourish the world using the fewest resources possible, while improving the availability, access, and utilization of food resources over time. A sustainable food system should not only minimize negative impacts to our planet but should also integrate agricultural development, climate action, and biodiversity conservation in order to contribute to agro-ecological resilience and to positive human nutrition and health outcomes (IPES-Food 2016). Tirado and Lengnick (forthcoming) identify six key principles of nutrition-sensitive and health-promoting sustainable food systems

- Promote production of diverse and nutrient-rich foods: There is a need to enhance the quantity, nutritional quality, and diversity of agricultural food production for local consumption of diverse diets.
- Respect the socio-cultural context: Strategies must be suitable for the microclimate, the local and community needs, and the socio-cultural context.
- Promote healthy dietary patterns and food safety: These can lead to both a reduction in GHG emissions and improved public health and nutritional outcomes.
- Target the most vulnerable groups and ensure social inclusion and resilience: Social protection is critical through increasing households' income, strengthening rural and urban services, and investing in sustainable agriculture so households become less exposed, less sensitive, more adaptive, and more resilient to a range of shocks.
- Ensure gender sensitivity: Women serve as agents of social change and development through their unique roles in their family and child care, livelihood generation, household food provisioning, and health and natural resource stewardship.
- Adopt a multi-sectoral approach and good governance: A number of policy, institutional, and governance solutions are necessary for the establishment of nutrition-sensitive and health-promoting sustainable food systems requiring a multi-sectoral approach.

We propose at least two additional principles should be added to this. First, there is a need to enhance demand for a diverse array of nutrient rich foods. Second, one must ensure that the food system avoids or minimizes the risks of exposure to harmful chemicals, pathogens and hazardous working conditions. The challenge, of course, is putting these principles into practice. Chapter 8 encompasses several case studies that illustrate trade-offs and strategies while Chapter 9 illustrates ways in which these principles can be implemented. As seen above, creating an environment conducive to optimal human health is extremely challenging. Human health that allows individuals to reach their potential is partially a function of individual behaviour, which is always within the context of the food system and the general environment in which they live. A person living on less than $2 per day probably cannot be expected to eat five servings of fruits and vegetables (with the right distribution to get sufficient levels of micronutrients), whole grains for sufficient fibre, and the proper level of protein without help. Similarly, a person cannot be expected to eat properly if they do not have relatively simple access to markets that have all of these in abundance.

Personal choices are made within a context of what the built and natural environment provides; they are made in the context of their cultural heritage; they are made in the context of finances and competing needs; they are made in the context of advertising and market placement – typically skewed to high-calorie, low nutrient foods; and they are made in the context of their world view. That is why the type and structure of a community's food system, the government and private sector policies that guide action and infrastructure development, the education (formal and informal) that is supported and encouraged in communities, and the community norms that evolve over time are critical to all of a community member's health and well being. In the public health world this is known as the social ecological context for human behaviour. The approaches we take – a food system approach rather than a narrow problem solving approach; a systemic approach rather than a single function approach will be important to multifaceted change. As illustrated in **Figure 4.12** the breadth of our lens matters to the types of improvements and our ability to reduce the level of unintended consequences.

Trends are illustrative of how we are doing and where we are headed. In general, as outlined above, the average dietary pattern of the developed world is neither conducive to optimal health nor to environmental sustainability. There is movement among a subsector to reduce meat consumption (witness the increased level of vegan and vegetarianism) with the proposal of the Chinese government to reduce it by 50 per cent among its population (Milman and Leavenworth 2016), and yet as of now, rates of consumption are still quite high. At the same time, at least a billion people would benefit from more animal protein in their diet, although this number could be reduced by treatment for parasites. The same can be said in the opposite direction for fruit, vegetable, and whole grain consumption. There is also a trend for increased developed world food dollars being spent on food produced under a number of certifications, such as organic (with a global market increase from US$15.2 billion in 1999 to US$80 billion in 2014 [IFOAM 2016]), biodynamic, and fair trade. These are impacting the landscape and some of how labour is treated across the globe, although this is clearly not enough. New research indicates the potential to feed the world (with nitrogen limitation problematic) through organic production and a concomitant reduction in food waste and animal production (Muller *et al.* 2017).

In the developing world, the challenge is one of the nutrition transition standing side-by-side with hunger – the double burden of obesity/overweight and undernutrition (WHO 2016a). Obesity is prevalent across a range of nations (Ng 2014), many of which also have high rates of undernutrition. The broad challenge here is to meet in the middle – increase the diversity and regularity of a healthy food supply across the economic strata while not increasing meat and empty calorie consumption dramatically.

It is clear from the range of studies cited here, as well as others, that a healthy and more environmentally sustainable diet would be one much lower in meat than the current U.S. (or EU average) intake with a much more plant-centred approach to protein, much higher in fruits and vegetables, higher in whole grains, and much lower in highly and ultra processed foods. It is also clear that severely reducing the use of the range of pesticides currently employed in modern production would lead to health improvements. Reducing and targeting nitrogen and phosphorus fertilizer use in places where it is overused would also be very helpful environmentally, and in some cases also improve human health.

A variety of policies, from global trade agreements to local municipality sugar taxes to production practice mandates, are being used and/or recommended as strategies for improvement (e.g. Colchero *et al.* 2016). Hawkes' (2017) notion of policy coherence in the context of the SDG aspirational narrative at the beginning of this chapter is a useful touchstone. Do policies have a positive impact relative to the targeted SDG and, at a minimum, do no harm to the improvement of others? A WHO (2016c) report outlines a number of recommendations for greatly reducing childhood obesity - the sum total of which argues for much greater coherence between trade, agricultural, and health policy.

The NAFTA example is also illustrative of negative human health and livelihood impacts of unfettered global trade. Others argue without appropriate trade it would be difficult for many countries to provide adequate nutrition to their current populations (not to mention future populations) (Wood *et al.* 2018). This is a testable notion in communities and regions across the globe. It has also been argued that a more nuanced notion of agricultural trade is needed. As of now, the dominant priority in trade is – efficiency (defined very narrowly) –while social goals of food rights, livelihood and environmental protections are ignored (Clapp 2014). We would argue that these social goals must be prioritized if an integrated approach to the SDGs is to succeed – something that global trade agreements currently do not recognize. There are examples across the globe illustrating production diversity and market access implications to smallholder farmer health and well-being HLPE 2017) - policies that encourage such diversity positively impact peoples' lives.

The Global Panel on Agriculture for Food Systems and Nutrition (2016) report has a similar message, namely that policy should be explicitly pointing to healthy diets. We would add that these should simultaneously incorporate environmental sustainability and human livelihood dimensions. A policy of farm diversification for improved nutrition should support agroecological methods of production as well as provide upstream infrastructure for market access and crop post-harvest management.

What is also fairly clear is the value of more regionalized food systems – food systems with a dynamic blend of regional and global, traditional and modern with a slant towards regional/traditional to the extent feasible in a particular region. This is also an area ripe for research and action. In the developed world, this has taken the form of creating short supply chains, direct sales to consumers, the emergence of food hubs, and the growth of smaller-scale agriculture among other developments. This approach has great potential, but needs to be implemented more broadly. In the developing world the most logical first steps may well be preserving and enhancing the regional food systems that already exist – supplementing them with global supply chains of healthy food – but fundamentally building upon existing informal and formal markets. Enabling people and communities to take this approach in a manner that fosters universal food and nutrition security while enhancing environmental integrity and livelihood security is imperative and achievable. TEEBAgriFood provides a Framework for determining strategies with the potential to markedly improve the situation of this wicked problem and insure the global population as a whole have the opportunity to live healthy lives, free from the twin scourges of obesity/overweight and undernutrition. A detailed description of the TEEBAgriFood Evaluation Framework (Chapter 6), the methodology (Chapter 7), case studies applying the Framework (Chapter 8), and the TEEBAgriFood theory of change (Chapter 9) can be found in other parts of this report. Coupling this to both the SDG's and the UN Decade for Action on Nutrition provides a powerful way to move forward and ensure global food and nutrition security.

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CHAPTER 5

SOCIAL EQUITY, JUSTICE AND ETHICS: MISSING LINKS IN ECO-AGRI-FOOD SYSTEMS

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SUMMARY

Chapter 5 explores the impact of food systems on key aspects of social equity and justice, addressing particular ethical considerations related to hunger, sustainability, human rights, safety, marketing, trade, corporations, diets and animal welfare among others. The chapter identifies key components of food systems to promote equity from production to consumption, to food waste management. In an equitable food system, everyone has access to healthy food and the benefits and burdens of the food system are equitably distributed. These require policies that ensure poor people's access to land, natural resources, technologies, markets, rights and gender equality. The chapter concludes that social equity, justice and ethical considerations should be fundamental values of our food system and the Sustainable Development Goals (SDGs).

CONTENTS

FIGURES, BOXES AND TABLES

CHAPTER 5

5.0 KEY MESSAGES

- This chapter explores the ways our food systems impact key aspects of social equity and justice and addresses particular ethical dilemmas within this context. This chapter identifies key components of equitable food systems along with policies and strategies to promote more equitable food systems.
- Social equity, justice and ethical considerations should be fundamental values embedded in our food system from production to consumption.
- In order to be sustainable the global food system should be equitable and meet the needs of present and future generations in its products, services and outcomes, while ensuring profitability, environmental, social and economic equity, and justice.
- Ethical considerations are inherent to complex food systems, modern agriculture and food technologies. They range from issues related to sustainability, safety, marketing and trade, to dietary choices, the role of corporate power, treatment of animals and the use of crops for energy and feed in a world affected by hunger and malnutrition.
- In an equitable food system, all people have meaningful access to sufficient healthy and culturally appropriate food, and the benefits and burdens of the food system are equitably distributed.
- Equitable food systems require an adequate policy environment that improves poor people's access to land, water and other natural resources, ensures labour rights, provides access to new technologies; creates access to local and international markets; and invests in improving gender equality and women's education and status.
- Social Equity is a critical component of most Sustainable Development Goals. The TEEBAgriFood Evaluation Framework provides a tool to collect and organize information and data on social equity related to food systems in order to assess progress towards the SDGs, considering all the components, institutions and policies of the food system, from production to processing, trade, distribution, and consumption, while also considering issues such as access and food waste management.

CHAPTER 5

SOCIAL EQUITY, JUSTICE AND ETHICS: MISSING LINKS IN ECO-AGRI-FOOD SYSTEMS

5.1 INTRODUCTION AND SCOPE

Social equity is a key aspect of the food system. It is one of the principal values underlying sustainable development, with all people and their quality of life being recognized as central (FAO 2014a).

In order to be sustainable, the food system must meet the needs of present and future generations with its products and services while ensuring profitability, environmental health and social and economic equity (FAO 2014b). Examining all aspects of the world's food systems, from production, to access, to trade and consumption to waste disposal, is critical in order to understand current performance and future sustainability.

Many international development plans such as the Sustainable Development Goals (SDGs), place importance on social equity and its relationship to poverty, hunger, obesity and inequality issues. At least 12 of the 17 SDGs contain indicators related to food systems and nutrition, and many of them reflect the importance of equitable food systems to the achievement of sustainable development.

TEEBAgriFood is designed to: i) provide a comprehensive economic evaluation of the eco-agri-food systems' complex, and ii) demonstrate that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive, and a lack of awareness of dependency on natural, human and social capital. The TEEBAgriFood Framework offers a tool to assess the costs and benefits of social equity of different food systems considering all their components, institutions and policies, and their entire value chain (i.e. from production, processing, trade and distribution, to access and consumption, including food waste management). It thereby enables better informed decision-making in governments, businesses, farms and consumers' choices (see Chapter 7).

The overall objectives of this chapter include: i) identification of key social equity and justice issues, and their determinants and impacts, as they relate to the world's food systems, ii) identification of the main aspects of equitable food systems, and iii) a look at existing policies and strategies that promote more equitable food systems. **Figure 5.1** presents a conceptual illustration used by the chapter for the analysis of the main social equity and social justice issues related to the food system through the stages of production, processing distribution, access, retailing, marketing, consumption and waste management. The chapter includes a discussion of selected ethical considerations in the social equity, justice and agri-food systems' context and presents policy options that could contribute to the promotion of more equitable agri-food systems.

5.2 EQUITY, JUSTICE AND ETHICS IN FOOD SYSTEMS

Equity is a key element of social justice, one that includes the concept of equality and also encompasses fairness and inclusiveness. The concept of equity also takes into account resource distribution and access to opportunities and decision-making (FAO 2014a). There are many cases in which fairness refers primarily to protection of the weak and the vulnerable (Johnston 2011), yet concerns related to equity pervade all social groups, since it is a crosscutting issue.

As such, equity encompasses rights, control over resources, subjective views (people's views about their well-being), capabilities (what people are objectively able to be or to do) and access to primary goods. Technically speaking equity can be assessed from a comprehensive perspective by using multidimensional evaluative spaces (Sen 2017). This means that no single aspect or dimension can full capture the concept of equity and that considerations always involve interpersonal comparisons of welfare (Ravallion 2016).

Figure 5.1 The food system and related social equity, justice and ethics issues (Source: authors)

Experts tend to focus on or emphasize multidimensional aspects of equity, such as human rights and avoidance of deprivation (Dasgupta 2004; Sen 2009), protection of livelihoods or basic needs or capabilities (Sen 2017) or equality of opportunities (Roemer 1996; Roemer 1998). The question of the best informational space to evaluate equity brings up questions of power and privilege in terms of gender, race, place of birth, social milieu, poverty etc. (World Bank 2006). Different authors use different informational spaces to analyze inequality and poverty issues in food systems.

In the context of sustainable food and agriculture systems, equity concerns arise when looking at the comparable distribution of productive resources, opportunities of employment and social services (e.g. education, health and justice), gender and ethnic inclusiveness and inter-generational opportunity (FAO 2014a). Equity is related to equality in terms of allocation of resources and people's freedoms and responsibility in these allocations, including gender issues (Freeman 2007; MA 2005). Food security and food system sustainability are ethical goals, and are rooted in fundamental ethical principles such as respect for human dignity and justice.

Justice is the principle that covers the institutional dimensions of ethics, and the guiding reference to guarantee equality, fairness and equity between citizens within a society and between all societies. The concept of justice embraces moral values which are relevant to agriculture and food systems (European Communities 2008), including:

- Distributive Justice: which guarantees the right to food on an equitable and fair basis;
- Social Justice: which protects the most disadvantaged in society and equal opportunities, which guarantee fair trade at national and international levels;
- Intergenerational Justice: which safeguards the interests of future generations.

Respect for human dignity is a fundamental right and a universal ethical principle which entails fundamental human rights, such as the right to food, the need to respect individual freedom, self-determination and well-being (see Section 5.3).

5.3 THE RIGHT TO ADEQUATE FOOD, LIVELIHOODS AND OTHER HUMAN RIGHTS

Equitable food systems and ethical principles such as the right to food, to health, to livelihoods, to a healthy environment and the rights of future generations to inherit natural resources are overlapping and complementary (European Communities 2008). A rights-based approach towards equity and can help address questions of equitable food systems, particularly related to hunger, health, the use of land, water, natural resources, livelihoods, labour, and technology.

Both the Universal Declaration of Human Rights and the Universal Declaration on the Eradication of Hunger and Malnutrition state that every human being has the right to nutritious food that will lead to their full development physically and mentally. For the Special Rapporteur on the Right to Food, the right to food is the right to have regular, permanent and unrestricted access, either directly or by means of financial purchases, to quantitatively and qualitatively adequate and sufficient food corresponding to the cultural traditions of the people to which the consumer belongs (OHCHR n.d.).

In addition to food security, an equitable food system must also offer good conditions for decent livelihoods (Maxwell 1996). Billions of people do not have an adequate standard of living, particularly in rural communities in developing countries, among populations displaced due to environmental crises, and among vulnerable groups such as poor women and children. Over-exploitation of natural resources impairs resilience to shocks and economic crises, resulting in significant job and land losses, which add to negative impacts on livelihoods (FAO 2014b). Equitable food systems have a critical role in ensuring food security and providing sustainable livelihoods for vulnerable communities.

From a sustainability perspective, the right to food and to a healthy natural environment are inextricably related, since environmental degradation jeopardizes the planet's capacity to meet rising food needs (Von Braun and Brown 2003) and economic development opportunities.

Economic development needs to be inextricably related to ethics and to be based on sustainability of natural resources and food security.

Ethical dimensions of the food system can be related to: policy design (e.g. malnutrition unsustainable use of natural resources, impacts on climate change, environmental health, biodiversity loss, etc.), producers' and consumers' choices, and the use of new technologies the food systems and any unexpected consequences that may arise.

As the nature of threats of the food system to health and the environment become more complex, uncertain and global in nature, the precautionary principle has been increasingly considered. This principle states that, in the case of serious or irreversible threats to the health of humans or the ecosystem, acknowledged scientific uncertainty should not be used as a reason to postpone preventive measures as provided for in Principle 15 of the Rio Declaration on Environment and Development (UN 1992).

5.4 SOCIAL EQUITY IN DIFFERENT ACTIVITIES OF THE FOOD SYSTEM

In an equitable food system, all people have meaningful access to sufficient healthy and culturally appropriate food, and the benefits and burdens of the food system are equitably distributed (Kessler and Chen 2015). **Table 5.1** shows how the concept of equitable food systems encompasses the effects of the production, processing, manufacturing, distribution, trade, retail, access, consumption of food and waste generation.

It is important to acknowledge that an equitable food production system is one that benefits people and groups that are disadvantaged or discriminated against, and it is vital in facilitating the reduction of poverty, through increasing food security as well as through providing broader economic development opportunities (Von Braun and Brown 2003; Kessler and Chen 2015) and decreasing diet-related diseases.

Table 5.1 Conceptual matrix for the analysis of social equity and justice in eco-agri-food systems (Source: authors)

	Production Processing	Trade Commercialization	Distribution/Access Consumption	Waste Management
Human Rights	Rights of poor agriculture/food workers The right to healthy environments Right to seed	Decent Livelihoods	The right to food The right to health	The right to a healthy environment
Livelihoods	Wage Level Capacity Development		Access to healthy food Quality of Life	
Ethical issues	Corporations- seeds patents New technologies Animal welfare Land grabbing	Code of Ethics (Codex Alimentarius) Fair Trade and Ethical certifications	Food price Malnutrition Excessive meat consumption	Food waste Hazardous waste
Employment Conditions in Production Processing Distribution Retail	Child labour Forced labour Gender equality and equity Labour rights Occupational Health	Gender equality Labour rights	Child labour/Forced labour Gender equality Labour rights Income equity	Occupational Health
Production Conditions	Farm size Monoculture vs. Agro-biodiversity Fair Access to Means of Production Capacity building Indigenous knowledge	Subsidies	Food price Food diversity Indigenous diets Food Sovereignty	Food losses and waste Capacity building
Environmental Issues	Environmental justice Ecosystems services Biodiversity conservation	Environmental justice	Biodiversity Environmental Health	Environmental justice Waste reduction and management
Health equity	Food safety Occupational safety/ exposure	Food Safety Standards Labelling	Nutrition Diet-related diseases	Environmental Health
Fair Trade	Rights of producers Local economy	Responsible Buyers Fair Pricing Certification Labelling	Fair salaries to access food	Waste reduction and management

5.5 FOOD PRODUCTION AND PROCESSING – EQUITY ISSUES

A growing population means ever-increasing food demand and corresponding pressure on global food systems to accelerate production. Equity in food production systems is then vital in assuring that this acceleration brings benefits and does not exclude the world's poor (von Braun and Brown 2003). Land and water systems in the major food producing regions of the world are at risk from intensive agricultural practices, which are degrading prime agricultural land, depleting non-renewable groundwater and competing with rapidly growing municipal and industrial uses. Competition for scarce land and water resources is at critical levels and is expected to intensify through 2030 (FAO 2011). Impacts of global warming and the acceleration of the global hydrological cycle will combine with resource scarcity to threaten the stability of the global food system in supplying even key staples to vulnerable populations.

5.5.1 Food demand, climate change and equity

By 2030, food demand is estimated to be 35 per cent higher than today (see **Table 5.2**) with higher needs arising in cities as the world urbanizes. Developing countries are expected to shoulder much more of the production burden, although regional variations in productivity are significant. Overall projections, in the absence of climate change, suggest that the current production model could deliver the food needed for this higher rate of consumption (although not always, nor necessarily in the desired quality and diversity).

Climate change presents an added challenge, as illustrated by **Figure 5.2** The majority of the increase in food demand is likely to come from regions and countries where production increases will be more vulnerable to the impacts of climate change. With 1.5-2oC higher temperatures, median estimates suggest a 15 per cent reduction in global crop yields. **Table 5.2** shows that the largest food demand increases are projected for animal protein (meat, fish, and dairy products) in developing countries, which is also associated with high greenhouse gas emissions (Hedenus et al. 2014).

Table 5.2 Largest increase in food demand by 2030 is projected for the poorest regions (Source: derived from Alexandratos and Bruinesma 2012) Percentage change in projected demand for food products between 2005-07 and 2030 (per cent)

	World	Developed countries	Developing countries	Sub-Saharan Africa	Near East and North Africa	Latin America and the Caribbean	South Asia	East Asia and the Pacific
Cereals, food	28	6	34	94	42	27	37	14
Cereals, all uses	32	23	38	-	-	-	-	-
Roots and tubers	35	1	52	75	50	23	75	9
Sugar and sugar crops (raw sugar eq.)	38	3	52	107	47	23	65	42
Pulses, dry	36	10	39	103	30	19	24	9
Vegetable oils, oilseeds & products (oil eq.)	47	12	70	110	59	40	85	60
Meat (carcass weight)	45	16	69	109	90	50	189	59
Milk and dairy, excl. butter (fresh milk eq.)	40	13	66	82	61	41	76	71
Other foods (kcal)	34	13	45	79	50	36	63	32
Total foods (kcal)	35	9	43	93	48	31	50	26

Figure 5.2 Climate change is projected to reduce crop yields in regions where food demand is projected to increase most (Source: adapted from WRI 2013)

A report by the World Economic Forum (WEF 2017) illustrated various scenarios, all of which present challenges for social equality in light of climate change. Climate change will have a negative impact on the productive capacity of food systems and exacerbate inequalities among the population of a given country and between nations. Though poverty overall is decreasing, inequality within and between nations means that the benefits of global prosperity are not universally shared (WEF 2017). Information about the global structure of agriculture and nutrient production and its diversity is essential in order to improve understanding of national food production patterns, agricultural livelihoods and food chains, and the potential impact of climate change.

5.5.2 Access to the means of food production

Land tenure, land use regimes, farm size and policies related to these concepts are fundamental factors that affect the sustainability and equitability of food systems. Land reform is still needed in many countries; access to land by landless rural people, and other forms of land distribution or consolidation still need to be addressed. Who owns the land, how they use it, and who controls land transactions all significantly influence equity in rural areas. Ideally, land policies should prioritize the protection and realization of the right to food above the creation of a market for land rights (de Schutter 2010). This is relevant in many African countries where land is considered to be State-owned, and treated by governments as if is it were their own; in Latin America, where agrarian concentration is on the rise (Latin America remains the region with the highest level of land inequality, measured by land Gini); and in South Asia, where many populations are being driven off their land to make room for large palm oil plantations or special economic zones (de Schutter 2010).

When other influences on land productivity are accounted for, the degree of land inequality is found to be negatively related to agricultural land productivity. This suggests that the distribution of land within countries is not optimal and land markets are not functioning properly. Beyond agricultural productivity, land inequality has been shown to have a negative impact on other key aspects of economic development—education, institutions and financial development—and on poverty (Erickson and Vollrath 2007).

Box 5.1 Critical issues in Latin America: inequities in land distribution

World Bank (2007) indicates that, in Latin America, land tenure and administration remain plagued by inequities in land distribution despite a history of land reform that attempted to address such issues. Although many land reforms did not successfully address inequity, the government did put in place a tenure system and institutional structure that sets Latin America apart from other regions of the world. Latin America contains a significant area of land claimed by indigenous peoples, demarcated by a separate tenure category that mandates a land administration structure entirely different from the mainstream national structures.

The legal protection of access to productive resources, including in particular land and water, is vital for the rural poor. Small farmers or indigenous communities have frequently been driven off the land they depended on for their livelihoods by the establishment of large-scale plantations, particularly related to biofuel production, and by construction of dams, tourist resorts, or other large-scale infrastructure or industrial projects. A lack of priority given to smallholders and family farming in national policies has diminished access to financial resources for these groups, which make up a large section of the world population (Wolfenson 2013). Industrialized agriculture has contributed to the global environmental and employment crisis and disconnection from local realities (Wolfenson 2013).

Farm size and diversity of agricultural production vary substantially across regions and are key structural determinants of food and nutrient production (Herrero et al. 2017). Small and medium farms (≤50 ha) produce 51–77 per cent of nearly all commodities and nutrients (Herrero et al. 2017). Despite their importance to food and nutrient production, small farms receive a disproportionate share of investment and policy attention. In order to ensure that the poor have increasing access to nutritious and affordable food in light of climate change, public policy should focus not only on increasing agriculture productivity to lower food prices in domestic markets, but also on promoting food production diversity as farm sizes increase in order to maintain the production of diverse nutrients and viable, multifunctional, sustainable landscapes.

5.5.3 Gender equality and equity

Gender equality and gender equity are different concepts. Gender equality refers to equal participation of women and men in decision making, equal ability to exercise their human rights, to access and control resources and to reap the benefits of development, and equal opportunities in employment and in all other aspects of their livelihoods (FAO 2013). Gender equity is fairness of treatment for women and men, according to their respective needs (IFAD 2015).

Gender equity is not often a specific objective in agrarian legislation. Women are key players in the agricultural sector, yet compared to men they are considered to be less productive because they own fewer assets and have access to less land, fewer inputs, and fewer financial and extension services. FAO (2011) has identified key factors that contribute to the existence of a gender productivity gap , including: i) land ownership, or long-term user rights, ii) access to agricultural credit, iii) access to productive farm inputs (including fertilizers, pesticides, and farming tools), iv) access to timely labour, v) support from extension and other rural advisory services, vi) access to markets and market information, vii) access to productive land, and viii) access to weather and climate information. If women had equal access to opportunities and resources as men, they could increase their farm yields by 20-30 per cent, feeding an additional 150 million people (FAO 2011).

5.5.4 Environmental justice and eco-agri-food systems

Environmental justice (EJ) is not universally defined, and has different meanings to various communities and institutions. The definition also varies according to place, time, and perspective. It is often explained using examples of environmental injustices, focusing on the distribution of environmental risks (see **Box 5.2**).

According to the U.S. Environment Protection Agency (EPA 1992): “Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment means that no group of people, including a racial, ethnic, or a socioeconomic group, should bear a disproportionate share of the negative environmental consequences resulting from industrial, municipal, and commercial operations or the execution of federal, state, local, and tribal programs and policies”. People who live, work and play in most polluted environments in America are commonly low income and people of colour. The EPA established an Office of Environmental Equity to address this fact (EPA 1992).

Box 5.2 Pesticide spray drift: an example of environmental injustice

Pesticide spray drift, i.e. the airborne movement of agricultural pesticide residue into residential areas, may pose serious health concerns in farming communities, leading to neurodevelopmental, reproductive and carcinogenic impacts (Shelton et al. 2014) Children living in close proximity to fields or in agricultural households have been found to have higher exposure to unsafe levels of neuro-toxic pesticides than their non-agricultural counterparts. Pesticide drift accidents have affected many living in marginalized and vulnerable communities in agricultural areas worldwide. The fact that pesticide pollution and illnesses associated with it disproportionately affect the poor and the powerless raises questions of environmental justice (Harrison 2011).

Box 5.3 Equity, equality, and autonomy: paradigms in environmental justice

Ideas about the meaning of environmental justice (EJ) differ in terms of concepts of equity, equality and autonomy. Equity and equality have been at the heart of most institutions' and many organizations' definitions of EJ. Some activists consider that EJ will be achieved through equitable distribution of environmental benefits, protection, and hazards, and equal treatment of communities (Peña 2003).

Equity, Equality and Autonomy have been defined in the context of environmental justice (Agyeman et al. 2003).

- Equity refers to freedom from favouritism when referring to a system of law; for instance, in the fulfilment of standards regarding environmental health. For example, the EPA established standards of acceptable air quality and the air quality for all communities should meet the standards.

- Equality refers to the same treatment and influence of all communities regarding environmental health. For example: Polluting industries should be distributed equally among the population and regions; thus, their air quality should be equal.

- Autonomy refers to the right of communities to be independent and self-governing when it comes to decisions that would affect environmental health. For example, communities should have a right to govern what type of air quality standards or how many polluting industries they want for their community beyond the minimum established by national / international norms.

EJ should not only be thought of in terms of the differentiated impacts of environmental pollution (brown issues) on communities and people, but also in terms of natural resource management (green issues). The pressure that demand for food worldwide is putting on natural resources is accelerating deforestation and land degradation, and leading to marginalization of people through conflicts over land, forests, water bodies and extractives worldwide. Box 5.4 offers an example illustrating the impact that increased agriculture production has had on deforestation, GHG emissions and land conflicts in Brazil.

Very often, the people most affected by deforestation are local populations and indigenous people that directly depend upon forest and soil resources for their traditional livelihoods (e.g. foraging communities). Unclear property rights and a lack of capacity to enforce natural resource preservation and management can lead to unsustainable use of land resources, especially when local populations do not have a voice to enact laws or enforce them.

Giving a voice to environmental groups and communities directly affected by such practices, like deforestation, is key in order to quickly arrive at compromises and incentives structures that allow for economic growth, food security and environmental justice.

The experience described in **Box 5.4** in Brazil is also common in other countries, and shows that large agri-food companies have a key role to play in the management of natural resources. Livestock (beef) and soy production are one of the main sources of deforestation and land degradation in Brazil, so producers at all scales must be involved in the related solutions.

Making agriculture production more sustainable is ever more imperative as food demand increases. The government of Brazil has established the largest incentive program worldwide (measured by volume of resources) for "greening" the agriculture sector ("Programa de Agricultura de Baixo Carbono – Programa ABC"), and the private sector has enacted related a "soy moratorium" with a promise not to buy soy from deforested lands. These measures are working and GHG emissions per head of cattle sold have been steadily decreasing and deforestation has dropped significantly in the past decade since the moratorium.

Box 5.4 Agriculture production, deforestation and land conflicts in Brazil

Brazil faces major challenges as it simultaneously pursues agricultural growth, environmental protection and sustainable development (World Bank 2010). Agriculture development and road expansion have been causing a steady increase in deforestation, as well as uproar in the international community as GHG emissions rise and local indigenous populations are pushed out of their lands. Brazil continues to be one of the worst offenders in terms of death due to land conflicts (U.S. Department of State 2015).

Brazil's forests and the Cerrado region represent an enormous carbon stock. The Amazon region, a reservoir of about 47 billion tons of carbon, sequesters more than five times the amount of carbon emitted globally each year – a huge benefit for the rest of the world.

The conversion of forestland to agricultural uses is likely to continue in areas such as the Cerrado region, which contains very large areas with untapped agricultural and forestry potential. With the continuing expansion of the country's road network, these areas are likely to become more accessible and thus more attractive to livestock investors increasing the risks of land conflicts with indigenous communities.

Food Justice

The concept of food justice is related to the environmental justice movement; it focuses on issues at the neighbourhood level, relates to the sustainable agriculture movement and incorporates issues of equity and social justice (Alkon and Norgaard 2009). Food justice accounts for racially stratified access to environmental benefits and draws attention to how that issue relates to the sustainable agriculture movement's processes of food production and consumption (Alkon and Norgaard 2009). The food justice concept has been used as a bridge between scholars and activists to connect the concepts of environmental justice, sustainable agriculture and food insecurity.

5.5.5 Ecosystems services and social equity

Ecosystems such as forests, wetlands, agricultural land and freshwater provide a variety of services1 that are economically valuable.

Arranging payments for the benefits provided by ecosystems is an innovative approach to conservation, recognizing their value and ensuring that the benefits of these natural functions continue in future.

Payment for Ecosystem Services (PES) are arrangements through which the beneficiaries of environmental services, from watershed protection and forest conservation to carbon sequestration, reward those whose lands provide these services with subsidies or market payments. In PES schemes, ecosystem services payments differ depending on the size of the land area put under conservation (on average, a smaller piece of land has a higher price per hectare) thus aiming to ensure a fairer distribution of funds between communities or wealthy landowners, and families (who tend to own smaller parcels, and for whom it may be more difficult to set aside land for conservation). PES schemes have also provided incentives for small landholders to group together in order to obtain economies of scale and gain eligibility for payment once conservation measures are adopted. Programs such as the Costa Rican PES scheme have matured over the years, establishing differential payments for activities that result in varying degrees of environmental service provisioning. While these activities might result in efficiency gains, resulting funds are not necessarily distributed equitably (Pagiola et al. 2004), urging the need to adopt fairness criteria into PES design (see more in Section 5.10.5).

5.5.6 Inequities of food-chain workers' health and occupational health

The International Labour Organization (ILO) considers the agricultural sector to be one of the most hazardous to health worldwide (ILO 2009). Millions of injuries occur to agricultural workers annually, at least 170,000 of them fatal (Cole 2006). Agricultural production facilities and fisheries have characteristics that are risky for safety and health including: exposure to the weather, close contact with animals and plants, extensive use of agro-chemical and biological products, lengthy hours and use of hazardous tools and large machinery.

Health hazards in agriculture range from relatively simple conditions like heat exhaustion to complex diseases like cancer. Exact data on levels of exposure and associated disease prevalence (or health effects) related to pesticides in the developing world are limited. Health

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1 Ecosystem services are defined by the Common International Classification of Ecosystem Services (CICES) as the contributions that ecosystems make to human well-being, and include provisioning, regulating and cultural services (EEA 2018).

and injury burdens depend on the type of farming activity, the type of worker, geographic location and inequities in occupational health services.

Migrant and seasonal workers in the food system constitute a particularly marginalized and underserved population with many unmet socio-economic and health care needs worldwide. Occupational hazards, poverty, substandard living conditions, migrancy, and language and cultural barriers contribute to seasonal agriculture workers' health problems and inequities in health care (Hansen and Donohoe 2003). In order to address the health care needs of workers in the food system, there is a need for stronger public health infrastructure, more data on specific health conditions in migrant and seasonal workers and improvements in education among workers and health care providers.

5.5.7 Labour rights

The agriculture and food sectors account for more than one-third of the world's labour force, and act as the second largest source of employment and the most important source of employment for women in many countries around the world (ILO 2018). This field faces some of the greatest challenges in working conditions and wages because of socioeconomic and historical trends. New factors now compound this issue, for example, the rise of informal employment, expansion of corporate regimes, and creation of neoliberal policies in the food system. These issues have disproportionate effects on the most vulnerable groups of workers including children, women, and other marginalized groups.

Labour rights are a range of rights enshrined in the ILO's Declaration on Fundamental Principles and Rights at Work (ILO 1998). Labour rights apply to food and beverage enterprises of all sizes and types (primary production, processing and marketing), as well as various types of ownership structures including cooperatives, single-family businesses, collectives, community-owned land trusts, tribal associations, and corporations, including both full and part-time producers, or business owners (FAO 2014b). Labour rights apply to all partners involved in the day-to-day management of a business operation, as well as all people employed whether full or part time, year round or seasonal (FAO 2014b).

Major worker issues occur across the food system, including child labour, forced labour, human trafficking, occupational health and safety malpractices, excessive working hours, gender-based harassment and discrimination, low and withheld wages and lack of legal status for immigrants. These issues can occur at any point in the chain including raw commodity production, both low-and high-value processing, wholesale/retail work or work in restaurants. Corporate food regimes can compound problems with low and irregular wages and lack of social protections through exclusion of workers from labour laws (Anderson and Athreya 2015).

Child Labour

Child labour and forced labour in food value chains pose major equity and ethical issues. ILO (2017a) defines child labour as work that deprives children of their childhood, their potential and their dignity, and that is harmful to physical and mental development. It refers to work that is mentally, physically, socially or morally dangerous and harmful to children, and interferes with their schooling by depriving them of the opportunity to attend school, obliging them to leave school prematurely or requiring them to attempt to combine school attendance with excessively long and heavy work. Over 70 per cent of all child labour occurs in the agriculture sector, and there are an estimated 100 million child labourers engaged in farming, livestock, forestry, fishing or aquaculture, often working long hours and facing occupational hazards and higher levels of risk than adult workers (Eynon et al. 2017).

According to an annual report produced by the U.S. Department of Labor (U.S. Department of Labor 2014), 126 different types of goods, including sugarcane, coffee, fish, rice, cocoa, alcoholic beverages and palm oil, are produced globally with the aid of child labour. Child labour not only violates children's rights by endangering health and interfering with education, it also creates an obstacle to sustainable development and food security.

Addressing child labour requires focus on its root causes, such as rural poverty and lack of social protection, and demands a look at food security among other issues (Eynon et al. 2017).

Inequity along the food chain: food manufacturing and processing

Workers across the food chain are often faced with low wages, dangerous working conditions and exploitation. For example, nine of the ten lowest paying jobs in the U.S. are in the food sector (U.S. Bureau of Labor Statistics 2016). While a number of factors contribute to this phenomenon, **Box 5.5** looks at how three factors in particular – immigration status, gender and race – affect wages in the food sector and processing plants in the U.S. from a legal and justice perspective.

Box 5.5 Main factors affecting lower wages in U.S. food sector and processing plants from a legal and justice perspective

Lee (2017) identifies three key factors contributing to lower wages in the U.S.: immigration status, gender and race. Studies from a number of different fields show an increased concentration of new Latino migrants in meatpacking communities particularly in the rural south. Many of the major processing plants in the U.S. are based in rural communities in states with weak labour law protections, which affects wages.

Gender also informs the type and severity of harms experienced by food workers. Although women tend to fare worse than men across industries, they fare particularly poorly in restaurant and farm industries. First, in the restaurant industry, women who work as servers routinely experience sexual harassment. Because of restaurants' antiquated tip-driven wage system, servers must please both their employers and customers. And while some servers at high-end restaurants might be able to rebuke harassing customers without imperilling their economic security, most servers cannot do so without a significant economic cost. Female farm workers have lower wages and regularly confront the threat of assault. The remote and rural nature of farms as workplaces erects a geographic barrier that makes policing these types of harms very hard.

Third, race continues to define working conditions and wages for many food workers. Existing scholarship has documented how race has figured into major shifts in farming policy and practices including race-based justifications to dispossess Native Americans of tribal lands during the 18th century (Saxton 1990; Walker 2007; Berger 2009) as well as the exclusion of farmworkers from New Deal protections, many of whom were the descendants of freed slaves (Linder 1987; Forbath 2001; Perea 2011). Less well-known is how a tip-based wage system exacerbates difficult racial dynamics within the restaurant industry. Under a tip-based wage system, workers can earn and keep whatever tips they may earn. But labour laws interpret these laws strictly, which means that in most cases, only those who work in the "front of the house" as servers, bartenders, and hosts are entitled to tips. Those who work in the "back of the house"—like cooks, dishwashers, and bussers—are excluded from this system. This wage differential exacerbates the racial dynamics that characterize many restaurants in which native-born whites work in the front of the house while immigrants, often from Latin and South America but also from Africa, the Caribbean, and Asia, remain in the back.

5.6 DISTRIBUTION AND ACCESS – EQUITY ISSUES

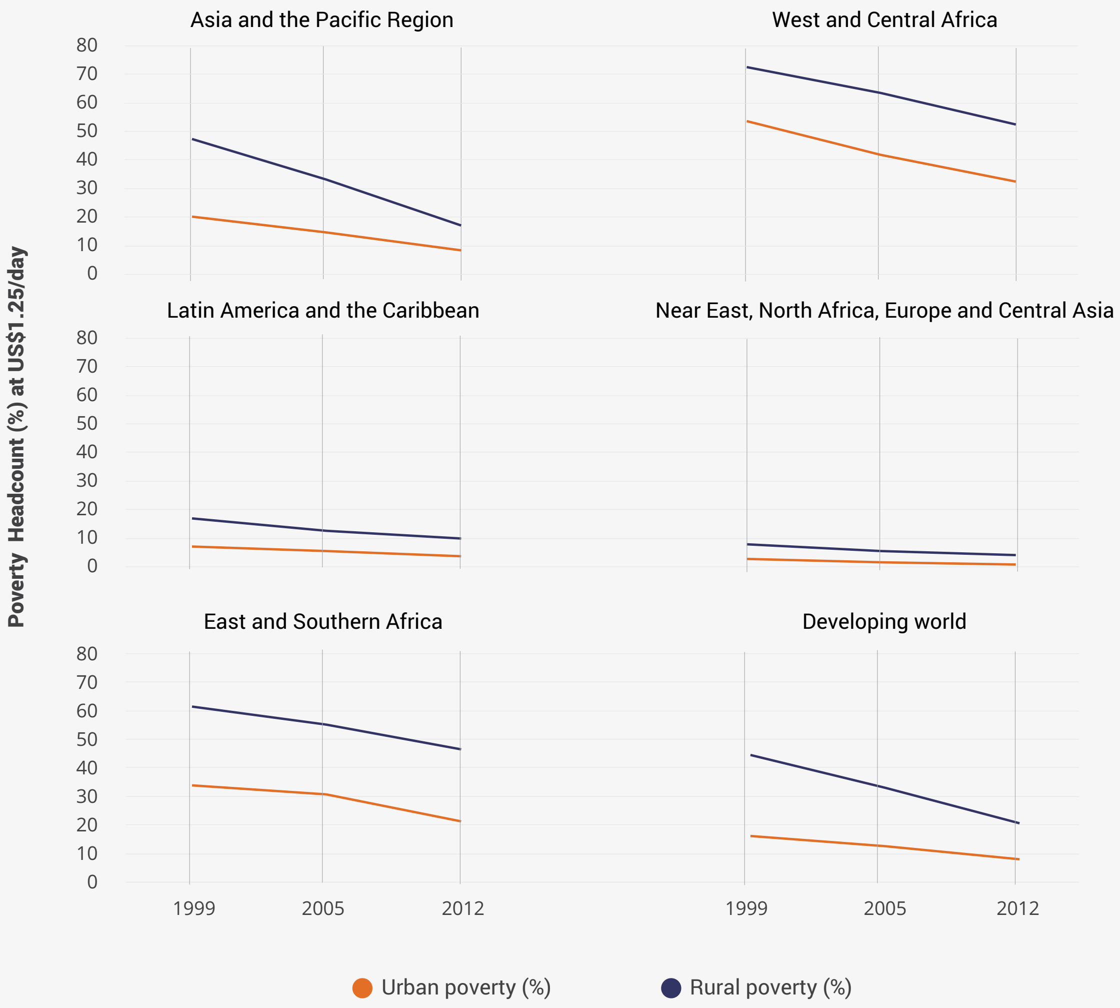
5.6.1 Poverty

Poverty is pernicious not only for its incidence but also for its depth (Ravallion 2016). In most regions of the world, poverty rates in rural areas are well above those in urban areas (See **Figure 5.3**). Problems in food distribution have especially negative impacts on children and the vulnerable. Approximately 23.2 per cent of children under five qualified as stunted in 2015, which represents a total of 156 million children in the world. The percentage of children under five who are wasted or severely wasted is 7.4 per cent and 2.5 per cent respectively. On the other hand, 42 million children under five are currently overweight (UNICEF 2017). More dramatically, perhaps, is the estimation that 45 per cent of the deaths of children under age five are linked to malnutrition (Black et al. 2013). Although poverty overall decreased from 44 per cent in 1990 to less than 15 per cent in 2012 (as defined by surviving on US$ 1.90 per day), there are many forms of malnutrition still prevalent in the world that are important from an equity perspective.

Incomes of the poorest people - most of them in rural areas and dependent upon farming for their livelihoods - will need to increase by about 4.5 per cent per year to meet the target of only 9 per cent of the world population in poverty by 2020 and the 3 per cent target by 2030 (Ravallion 2013; Yoshida et al. 2014). From 2000 to 2010, agricultural total factor productivity growth, a key driver of agricultural income gain, was about 1 per cent per year (Fugile et al. 2012) in the poorest regions, particularly in Sub-Saharan Africa. Continuation of this rate, even with projected migration rates, which would increase agricultural labour productivity, will likely leave real income gains below the needed 4.5 per cent per year, unless other, non-agricultural employment opportunities are provided in the rural space.

Raising the incomes of the rural poor is possible. The experience of Brazil shows how a country can go from a food insecure, net food importing country to a net food exporter with a drastic reduction in poverty and hunger. Agricultural productivity in Brazil has increased not only for the largest commercial farmers, but also for smaller family farmers thanks to macroeconomic policies that support the agricultural industry as a whole, along with specific agricultural policies targeting family farmers (FAO 2014c).

Figure 5.3 Trends in rural and urban extreme poverty by region (Source: adapted from IFAD 2016)

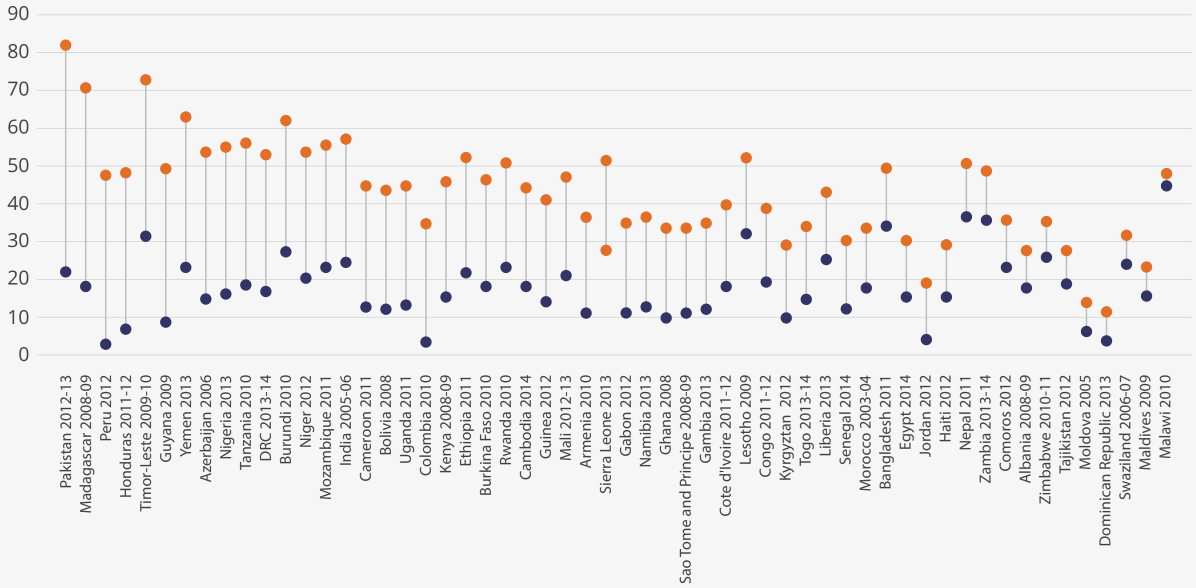


5.6.2 Economic and distributive inequality

World economic inequality, as measured by the Gini index of household income inequality, has increased from 38.5 per cent in the early 1990s to 41.5 per cent in the late 2000s (UNDP 2013). Despite the global financial crisis, the number of undernourished people in developing countries declined from over 23 per cent to roughly 13 per cent (FAO 2017). However, undernourishment trends are unequally distributed in the world with Sub-Saharan Africa and the Caribbean having 23.2 per cent and 19.8 per cent of the total world incidence of undernourished populations, respectively. There are also wide variations in stunting within countries, with many sub-national regions having stunting rates up to three times higher than the region with the lowest stunting rate (see **Figure 5.4**). One of the most important drivers is mother's age at birth. For instance, in Ghana and Uganda, 20 per cent more five-year-old children are stunted if born to women under 18 (IFPRI 2016). In addition, according to the FAO (2013), there are still two billion people in the world who suffer from one or more micronutrient (vitamins and minerals) deficiencies.

The food system has an impact on economic inequality and not only in developing countries. In the U.S., only 8 per cent of farmers on large farms (those with sales of US$ 250,000 or more per year) can live on farm income alone. The primary rights of American farmers are being neglected, as shown by: i) the failure of the U.S. food system to provide remuneration for farmers' labour that is enough to satisfy their family needs (including health care and social security), and ii) the failure to benefit from scientific progress and its applications (Anderson 2008). This happens in part because farming in the U.S. has not been able to generate many rural jobs because public policy and technology have benefited capital-intensive food systems (NRC 2002).

Figure 5.4 Stunting prevalence by subnational region (Source: adapted from IFPRI 2016)



According to FAO (2018a), global food prices have generally fallen over the last five years as a result of an increase in food supply (though a recent rise in food prices counters the general trend), as shown in **Figure 5.5**, and global hunger

5.6.3 Food prices and inequity

Food prices are important contributors to the overall picture of nutrition and health status. Food prices affect diets and diet choices, which are in turn the number one risk factor for the global burden of disease (IFPRI 2016). The poorest individuals spend a larger share of their income on food (urban poor can spend more of 50 per cent of their budget on food (World Bank and IMF 2012).

has fallen, from affecting around 19 per cent of the overall population in the early 1990s to below 11 per cent of the current population. The traditional link between food prices and poverty depends on the context. Indeed, rapid urbanization and population growth mean that food insecurity and malnutrition are increasingly becoming urban problems (IFPRI 2017). In addition, it is important to note that access to food has been much limited in areas with civil conflicts and areas suffering drought conditions in East Africa.

A good index of persistent of hunger due to higher food prices, seen as an extreme measure of inequity, can be revealed by the number of countries that require external assistance for food. There are currently 37 such countries, 28 of them in Africa (FAO 2017). However, FAO's composite food index should not be seen with extreme optimism because the markets for some foods such as sugar and oils have varied more than others, such as meat (their respective standard deviations during 2000-2017 were 52.6, 34.2 and 15.4, suggesting that food prices of sugar and oils have experienced more volatility than those of meat, as shown in **Figure 5.6**, whose consumption remains a key nutritional challenge for developing countries).

There is also great variability of food prices between cities in the same region (see **Figure 5.7**), which ultimately affects people's dietary choice and eventually health inequities.

The urban poor are particularly sensitive to food prices. As urban populations increase, food insecurity and malnutrition are increasingly becoming urban problems in all regions of the world (IFPRI 2017).

The minimum wage can be set to cover the minimum needs of a worker and his family, taking into account the economic and social conditions of the countries. The concept of Basic Food Basket (BFB) covers the goods needed to meet the nutritional needs of the population and is used to determine each country's extreme poverty line. Therefore, linking BFB to the minimum wage can help illustrate the degree of vulnerability of the poorest households in terms of food and nutritional security. For example, **Box 5.6** shows the relationship between the cost of the family BFB and the minimum wage for a sample of countries in Latin America.

Figure 5.5 Food Price Index (FAO 2018a)

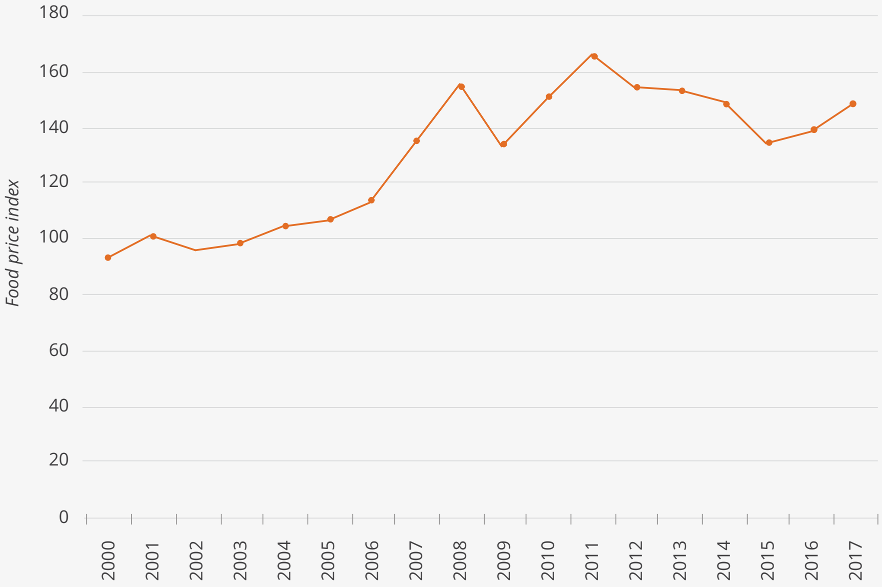
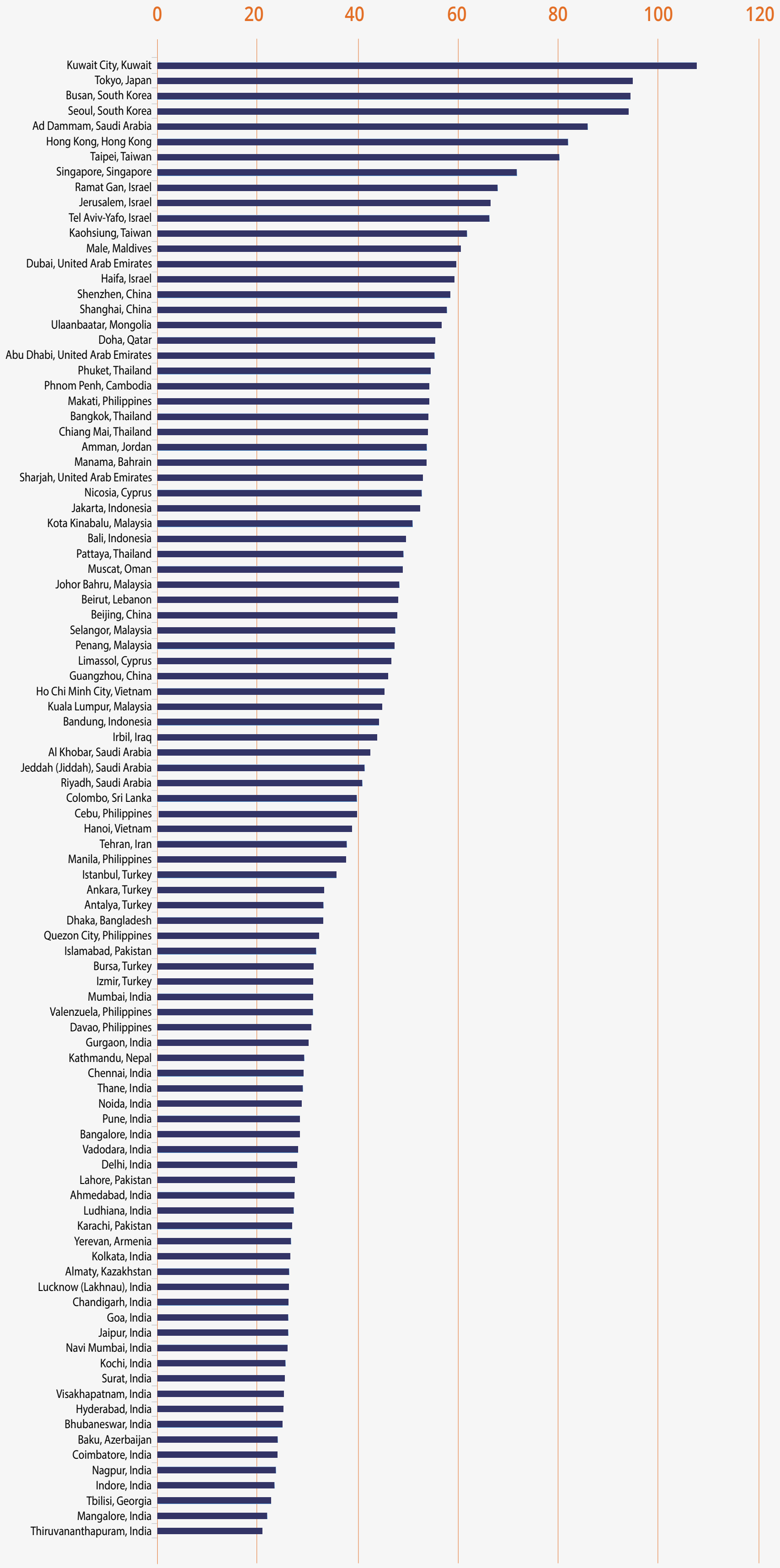


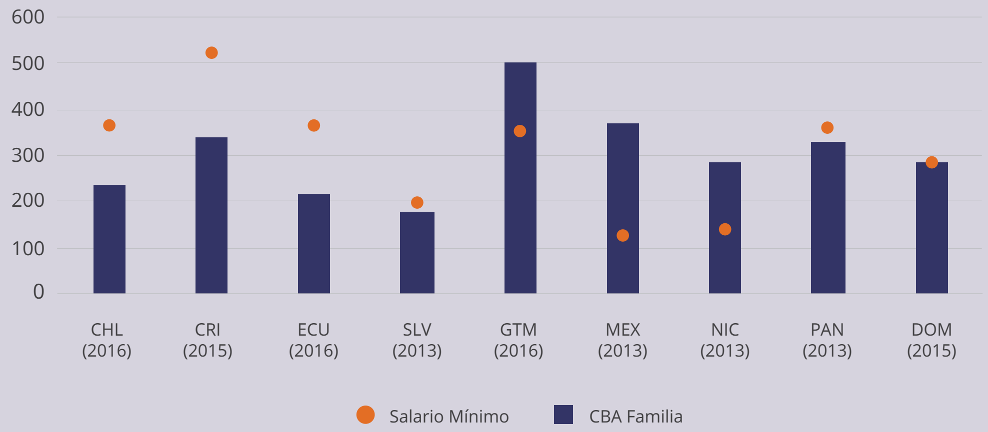
Figure 5.6 Food Commodity Price Indices (Source: FAO 2018a)

Figure 5.7 Cost of living in Asian cities (Source: Numbeo 2018)



Box 5.6 The relationship between food prices, minimum wage and vulnerability in Latin America

Figure 5.8 Figure 5.8 Basic Food Basket and minimum wage in a sample of countries in Latin America (Source: personal communication, FAO Regional Office for Latin America and the Caribbean, based on country data and ILOSTAT)



A sample of nine countries in Latin America were analyzed to assess whether minimum wage could cover the cost of a family BFB. Firstly, the variability between countries, in terms of both minimum wage and BFB, was significant. Minimum wage ranged from 129 to 523 between Mexico and Costa Rica, respectively, while the difference between cost of family BFB ranged from 174 to 499 in El Salvador and Guatemala, respectively. Secondly, the results themselves were mixed. Three countries (Guatemala, Mexico and Nicaragua) are all unable to cover the cost of a family BFB with minimum wage; three countries (El Salvador, Panama and Dominican Republic) were all barely able to cover the costs; and although the remaining three countries (Chile, Costa Rica and Ecuador) all earned sufficient amounts to cover the costs, it is still worth pointing out that more than half of their earnings were spent on food alone. Lastly, it should be noted that not all the basic needs of a family are included within the cost of a FBB; therefore, small variations in the price may put at risk the food security of the family group.

As global incomes rise and households with rising incomes spend a smaller share of that income on food, their patterns of food consumption tend to vary less even if food prices spike. With less downward adjustment of demand, the supply side (through production, stocks and trade) will need to adjust more quickly to production shocks in order to reduce overall price volatility and reduce the magnitude and frequency of price spikes over time. Current trade and social protection policies leave many poor people vulnerable to adverse nutritional consequences of food price shocks. The logistical capacity to transport food from areas of production to areas of demand is stretched in many food insecure locations. In addition, with increased population density, there is increased risk of the spread of livestock diseases.

Food price volatility and unexpected large swings in food prices creates hardship for low-income food consumers who spend most of their budget on food, and for poor farmers who depend on agriculture for their income. Governments have acted to try to safeguard the most vulnerable against such swings, but often with unintended consequences. To ensure the progressiveness of food support policies, targeting poor communities and families is key.

5.6.4 Food access, health and nutrition

Globally and within countries there are large inequities in relation to the access to, and the affordability of, nutritious and healthy foods. The food system plays a lead role in poor nutrition outcomes globally, which are linked to morbidity, premature mortality, high health care costs and lost productivity. While significant progress has been made on the Millennium Development Goal (MDG) for provision of adequate amounts of available dietary energy, progress on the MDGs for undernutrition (underweight) and stunting has lagged. Eliminating undernutrition within a generation will be challenging. If current trends continue, an estimated 450 million children will be affected by stunting by 2030 (De Onis and Branca 2016).

Obesity and inequities

Obesity has increased to the extent that the number of overweight people now exceeds the number of underweight people worldwide. Almost 30 per cent of the world's population, or 2.1 billion people, are overweight or obese, 62 per cent of whom live in developing countries (Ng et al. 2004) thus illustrating an important inequity.

Obesity accounts for a growing level and share of worldwide diabetes, heart disease, and certain cancers. The number of overweight children is expected to double by 2030. Driven primarily by increasing production of processed, affordable, and effectively marketed food (Swinburn et al. 2011), the global food system is falling short on – and arguably actively driving – rising obesity and related poor health outcomes. Due to established health implications and rapid increase in prevalence, obesity is now a recognized major global health and health equity challenge, and no national success stories have yet been reported (Ng et al. 2014). Over the past twenty years, a global overweight/obesity epidemic has emerged, including in low- and middle-income countries, resulting in a triple burden of undernutrition, micronutrient deficiency, and overweight/obesity. There is significant variation by region, where some have very high rates of chronic undernutrition (stunting) and low rates of obesity, while for other regions the opposite is true (**see Figure 5.9**).

There is a close link between food access and food security and nutrition. Whereas the relatively rich buy their food from supermarkets, many of the poor still rely on the informal sector where access to electricity for long-term refrigeration can sometimes be difficult. For instance, in many African cities, the urban poor buy most of their eggs, fish, meat and milk from informal markets. In countries such as Cote d'Ivoire, Kenya, Mali and Uganda, 80-90 per cent of raw milk is purchased from vendors or small-scale retailers whereas 90 per cent of households in the relatively richer cities of Cape Town and Johannesburg in South Africa buy their milk from supermarkets (IFPRI 2017).

Figure 5.9 Undernourishment and Obesity Rates Vary Significantly by Region (Source: World Bank 2015)

Box 5.7 Food access, consumption and lifestyle in transition economies

Food access is a fundamental equity issue. Evidence from South East Europe (SEE) and Eastern Europe, the Caucasus and Central Asia (EECCA) revealed that their food systems, highly specialized during the Soviet and Yugoslav legacies, changed dramatically during the political changes of the 1990s. The previous systems included large-scale farms, 'dachas' (plots of family land) and an overall state-run system that was highly centralized. Dismantling of the system of state-controlled agricultural production led to changes in ownership and access, with profound effects on people's health including the intensification of fertilizers and pesticides and changes in diets, places of food purchase and in attitudes to food labelling. Calorie intake decreased in most of EECCA countries during the recession of the mid-to late 1990s, but has recovered since then (Hak et al. 2013).

5.6.5 Health inequities

Health inequities associated with the food system are reflected in disproportionate rates of malnutrition, obesity and diet-related disease such as type 2 diabetes and cardiovascular disease among the poor. Health inequities are also related to occupational health, as seen through exposure to chemicals in rural agricultural communities.

Health inequities related to nutrition

Of the top 20 risk factors for health in terms of attributable mortality, 10 are related to nutrition (including four of the top six). While under-nutrition and micronutrient deficiencies continue to play an important role in morbidity and mortality in low-income countries, the largest nutrition-related burden worldwide now comes from energy-rich and often nutrient-poor diets, and by an excess consumption of foods high in salt, sugar and fat, in countries at all levels of income (Popkin et al. 2012). The most dramatic manifestation of this trend is the current obesity epidemic. Since 1980, obesity rates have doubled or tripled in many countries worldwide, and in more than half of OECD countries over 50 per cent of the population is currently overweight (WHO 2017).

Different dimensions of poor nutrition, as well as the burden of disease associated with them, are distributed unevenly within and between countries. Undernutrition and micronutrient deficiencies remain heavily concentrated in poor countries and affect predominantly (but not exclusively) the most disadvantaged groups in those countries, i.e. those who cannot afford nutritious foods and diets, or experience other access barriers.

Conversely, those forms of malnutrition linked to excess intake of calories of poor nutritional quality, often leading to obesity, have been spreading faster in high-income countries. Within countries, the distribution of obesity in different socioeconomic groups tends to follow different patterns depending on countries' income and level of development.

Obesity is especially prevalent in higher socioeconomic groups, particularly in men, in lower-income countries. The pattern is generally reversed in higher-income countries, where it is women of low socioeconomic condition who are most likely to be obese (Devaux and Sassi 2013).

In Europe, social disparities in overweight and obese populations are generally associated with national income. Roskam et al. 2010 found that a EUR 10,000 increase in per capita GDP corresponded to a three per cent increase in the rate of being overweight and obese among less educated men, and a four per cent decrease for more educated men, while no associations with GDP were observed for women. Obesity in women, especially during pregnancy, contributes to the health risks of their children and this amplifies health inequities across generations (Robertson et al. 2007; Loring and Robertson 2014).

Obesity and other conditions that are closely linked with nutrition, such as hypertension (linked with excess salt consumption) are among the causes of major chronic non-communicable diseases such as diabetes and cardiovascular disease (CVD). Globally, the majority of the burden of those diseases is attributable to dietary risks and excess body weight (IHME 2015). However, diabetes and cardiovascular disease are also distributed unevenly within and between countries. **Figure 5.10 and Figure 5.11** use Disability-Adjusted Life Years (DALYs) to show a larger than threefold variation in rates of disease burden across "GBD super regions"2, with diabetes generating the largest burden in the 'Latin America and Caribbean' and 'North Africa and Middle East' regions, while the highest rates of CVD burden are observed in 'Central Europe, Eastern Europe and Central Asia', with 'South Asia' and 'Southeast Asia, East Asia & Oceania' following at some distance.

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2 The Global Burden of Disease (GBD) study divides the world, for administrative and data analysis purposes, into seven "super regions", based not only on geographic location but also on country GDP (IHME 2017).

Like obesity, type 2 diabetes tends to be more prevalent in lower income populations than in high-income countries (IDF 2017), while it is often more common in the wealthier parts of the population of low-income countries, although these patterns tend to vary widely between countries. Inequalities in cardiovascular disease within countries tend to be associated more consistently with a greater burden of disease in low socioeconomic groups, partly reflecting the social distribution of smoking, a further major contributor to CVD.

Figure 5.10 Rates of disease burden of diabetes, all ages (Source: adapted from IHME 2015)

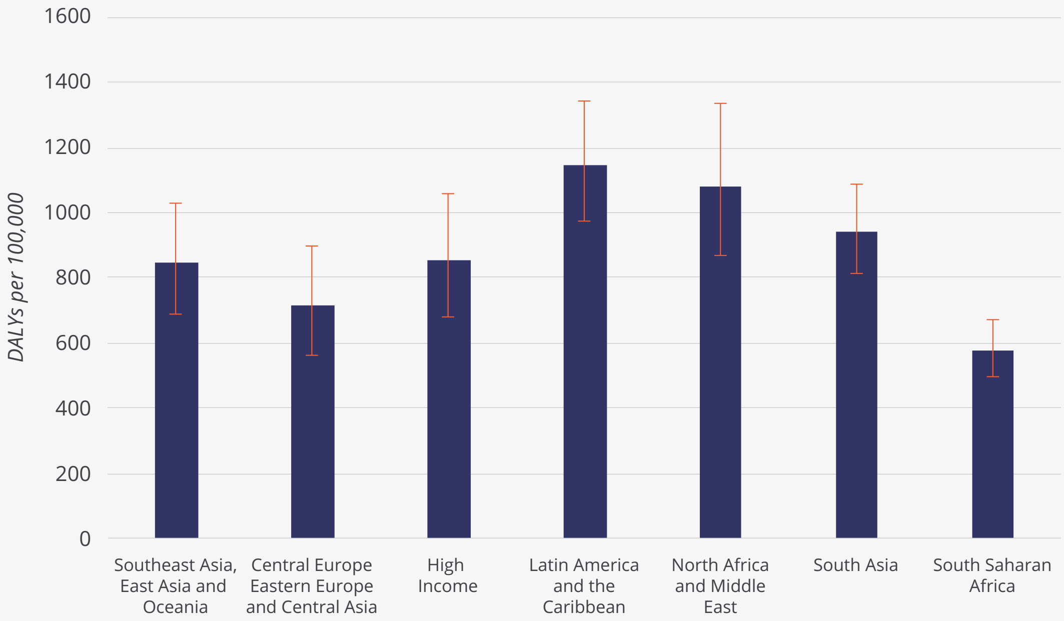


Figure 5.11 Rates of disease burden of cardiovascular disease (CVD), all ages (Source: adapted from IHME 2015)

5.7 FOOD TRADE AND EQUITY

Globalization of trade has led to unfair competition and hardships for primary producers in both developing and developed countries (FAO 2013). Several factors are at play, including country trade barriers. Primary producers are losing their land and are being driven to the cities by wars, environmental disasters, misguided public policy and economic desperation. All of these factors are leading to increased inequity (FAO 2013). The highly concentrated and multinational agricultural buyers often receive governmental support that distorts markets, encouraging pricing schemes that fail to reflect full costs to society and the environment while also failing to cover the full costs of production for primary producers (FAO 2014b). Food policies in developed countries that encourage or reward the undermining of fair trade practices negatively impact long-term sustainability and equity of primary producers (FAO 2014a).

Food production and trade play an important role in poverty reduction and shared prosperity. Poor households spend a large share of their income on food, and if food access and quality is not equitable, this can create further divergence in development outcomes in areas including health, education, and economic productivity. Environmental factors, such as climate change, also impact global food security and resource sustainability. As agricultural trade becomes increasingly important to national food supplies, the use of natural resources (land, water) can shift, leading to social and environmental externalities in food producing countries.

The food commodities that are globally traded are worth more than US$520 billion per year, could feed approximately two billion people, use about 13 per cent of worldwide cropland and pasture, and have geographically concentrated irrigation water demands (MacDonald et al. 2015).

When countries import food rather than produce it domestically, it can displace environmental problems abroad. For example, the expansion of production of palm oil, soy and meat has led to land-use change in tropical countries such as Indonesia and Brazil. The concentration of food exports in a few countries can create stress on natural capital in those countries and contribute even further to climate change and inequity. It can also put global food security at risk if those food sources are not sustainable or are sensitive to climate variations. The recent food price crises in 2007 and 2012 showcased these vulnerabilities; a combination of climatic factors, low inventories and export restrictions led to increases in international food prices above and beyond the initial shock. Often trade policies have reduced rather than increased the responsiveness of the food system to shocks. Those countries that concentrate natural resources (land and water) on supplying the food export market are mainly in the Americas, plus Australia and a few countries in Asia, Eastern Europe and West Africa; while the countries that are relatively disconnected from that trade are located in Sub-Saharan Africa, and South Asia (MacDonald et al. 2015).

The amount of food imported has little to do with food insecurity, and more to do with the competitiveness of domestic agriculture production. The problem begins when a country opens its borders to food imports (reducing import tariffs and barriers to trade) without properly preparing low-income farmers to compete with imported products. Poor consumers in urban areas benefit from low food prices, but if the rural population is not supported, this can cause an unexpected and sudden drop in agriculture production and in the income of the rural poor. Food trade deficits have ballooned in poor countries in recent decades, while these same countries should be taking advantage of local agriculture production to increase the income of the rural poor households. Therefore, many African countries are trying to follow the example of Brazil, which went from being a net food importing country to a net food exporting country in a period of 30 years. This trajectory is replicable for many agriculture-based economies in Africa and Asia, but it requires a set of macro- and sector-level policies that look at food trade (both imports and exports) as an opportunity rather than a threat. Furthermore, there is a link between countries that are less dependent on food trade and overall levels of poverty, in particular, rural poverty and undernutrition.

Considerations of health outcomes are rarely factored into food support policies or programs related to consumer goods. For example, the sugar market is one of the most distorted markets in the world. Small producers in less-developed countries cannot compete with countries benefitting from EU subsidies and support policies. Despite the fact that countries such as Mozambique and South Africa have the lowest cost of production, sugar farming cannot guarantee the livelihoods of small farmers there, with resulting impact on poverty rates in these countries (MA 2005). Thus, there is a clear link between food subsidies and policies in sugar markets and reduction of poverty and nutrition outcomes in these countries.

To develop equitable and sustainable trading relations, buyers should pay primary producers prices that reflect the real cost of the entire process of sustaining a regenerative ecological system (FAO 2014b). This includes inter alia supporting a decent livelihood for primary producers, their families and workers by providing living wages that cover producer's costs. Fair pricing becomes possible when buyers agree to negotiate with their suppliers on terms of equality before establishing contracts, whether written or verbal, that set the terms of trade.

5.8 FOOD WASTE – EQUITY ISSUES

Food is lost or wasted throughout the supply chain, from initial agricultural production to final household consumption. Food losses and waste impact food security and nutrition and the sustainability of food systems and their capacity to ensure good quality and adequate food for the current global population and future generations (HLPE 2014).

Nearly one-third of food produced for human consumption, approximately 1.3 billion tons per year, is either lost or wasted globally (HLPE 2014). One-fourth of the food currently lost or wasted globally could feed the 870 million hungry people in the world (Gustavsson et al. 2011). This is a clear indication of the inequity of distribution in the current food system. Food losses and waste often translate into economic losses for farmers and others stakeholders within the food value chain, and thus to higher prices for consumers; both factors contribute to making food less accessible for vulnerable groups (FAO 2017).

Without accounting for GHG emissions from land use change, the carbon footprint of food produced and not eaten is estimated to 3.3 tons of CO_2 equivalent. As such, food wastage (i.e. food waste and loss) ranks as the third top emitter after the U.S. and China (FAO 2013).

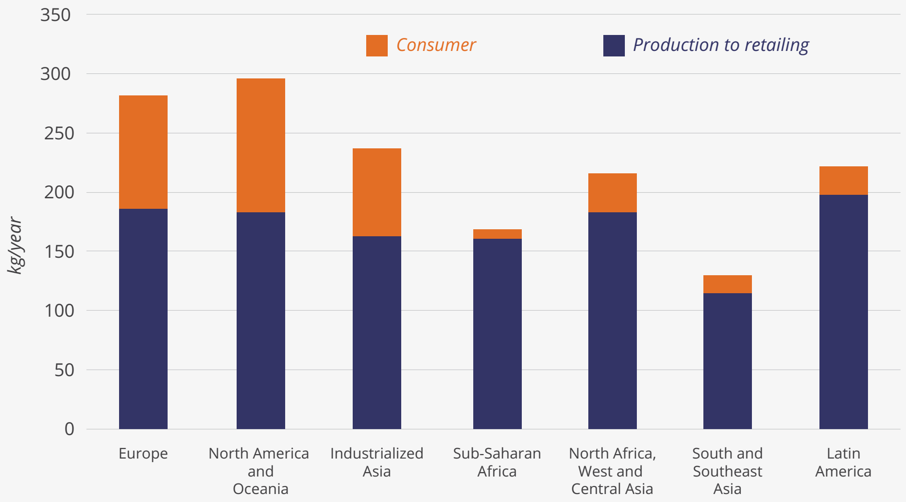
Food waste is a huge problem globally, but the underlying reasons for it differ between regions as seen in **Figure 5.12.** In medium- and high-income countries, losses tend to occur at the consumption stage, meaning that the consumer discards food even if it is still suitable for human consumption. Significant losses also occur early in the food supply chains in the industrialized regions. In low-income countries, food is lost mostly during the early and middle stages of the food supply chain before arriving at the consumer level (Gustavsson et al. 2011). Factors leading to food spoilage include lack of modern transport and storage infrastructure, as well as financial, managerial and technical limitations in difficult climatic conditions (Venkat 2011; Gustavsson et al. 2011).

The consumer share of food losses and waste can be very high in specific locations; for example, the amount of food wasted in one community in New York State in the U.S. in one year was sufficient to feed everyone in the community for 1.5 months. 60 per cent of the losses occurred after the food was purchased by the consumer (Griffin et al. 2009).

People's attitudes and approach to food waste can be altered in order to modify behaviour so as to minimize waste in the home, but technology is required to ensure that as little of the produce as possible is lost during distribution. The majority of losses in most countries occur during transit (Gustavsson et al. 2011). Technology, whether used in crop production, processing or distribution, can help to minimize losses.

Reducing food waste has enormous potential for reducing the resources used to produce food and can help lower the environmental impact of food production and consumption. Food waste prevention is an integral part of Europe's transition towards a circular economy, (EC 2016) which is expected to boost global competitiveness, foster sustainable growth and generate new jobs.

Figure 5.12 Food losses and waste at consumption and pre-consumption stages by region (Source: adapted from Gustavsson et al. 2011)



5.9 ETHICAL CONSIDERATIONS IN THE ECO-AGRI-FOOD SYSTEM CONTEXT

Food systems and their resulting economic benefits have an ethical dimension related to feeding the world's population and preserving the planet's food-producing capacity and natural ecosystems for future generations. A number of ethical considerations in food systems are related to food policies and inherent in modern agriculture and food technologies, ranging from issues related to food safety and sustainability, to marketing and trade, consumers' choices, the role of corporate power, and the treatment of animals (European Communities 2008).

5.9.1 Corporations and ethics

Asymmetries of power and market concentration in large agriculture and food corporations are one of several important ethical issues identified in the modern food system (Global Food Ethics Project 2015).

Large agribusiness corporations dominate increasingly globalized markets due to their ability to achieve economies of scale. The objective of profit maximization drives most of the decisions of corporations in the agri-food sector. It is necessary to explore policies that can direct corporations to internalize ethics since this can be more profitable on the long run.

One of the most significant ethical issues related to agri-food corporations is the issue of patents on seed, which leads to monopolies on genetic material, high seed prices and impingement of farmer's rights. A small number of corporations in developed countries control seed distribution for new and possibly better products (European Communities 2008). Corporations controlling the intellectual property rights to seeds means they can restrict access to new 'improved' varieties and make those choosing not to purchase the seeds less competitive in the market, potentially trapping farmers in a cycle of poverty.

Multinational food and beverage corporations with powerful marketing strategies have also been a driving force in the increase in the global consumption of processed foods that contain large amounts of salt, sugar, and fat as well as the consumption of sweetened beverages (Monteiro and Cannon 2012). These ultra-processed unhealthy foods have displaced traditional food systems and healthy dietary patterns, undermining public health efforts (Monteiro and Cannon 2012). The extent to which large scale agricultural and food marketing firms and corporations contribute to food security and nutrition is undervalued in ethical debates (Global Food Ethics Project 2015).

There are ethical concerns regarding the claims from large corporations that, to overcome the impacts of climate change, population pressure and increased food demand, the world must develop new technologies at a global scale. These new technologies for food production, however, have been leading to inequitable conditions, such as competition policy that favours a few corporate actors and the suspension of the precautionary principle (Rigaud 2008; IPES-Food 2017). These actions represent a challenge to ethics and equity (see next section).

5.9.2 Ethics of modern developments and technologies in the food system

Increasing food production may require changes to the way we grow crops, use chemicals, choose crop varieties, or position and size farms. All of these may have an impact on the environment, on sustainability over a long period of time, and on safety both when the crop is consumed and on those working on the land or harvesting and transporting the crop (see Sections 4.7.1 and 5.5.5).

New technologies in agriculture can help increase crop production and improve practices that benefit sustainability and food security for current and future generations (European Communities 2008). However, questions about the safety of these new technologies and their ability to address issues of poverty, hunger, malnutrition and loss of biodiversity remain.

For instance, modern biotechnology enables rapid changes to plants and animals. There are many gaps in the understanding of how, for instance, gene drive used as a set of technologies may impact the target organism, the environment, and subsequent generations. It is also essential to consider how gene drives will propagate throughout a population and affect not only the target species, but also its entire ecological community (NAOS 2016).

All of these new technologies may bring ethical considerations. Many concerns apply to modifications of plant species and animals. In the case of plants, the results of a disastrous modification or choices may impact on food availability and sustainability. In animals, the effect may be less disastrous to anything other than the particular breed, but ethically, whether we should introduce suffering to a group of animals for consumer gratification is something to be considered.

There is great concern that chemical residues, or genetic modification in food and feed may have an impact on those who consume the products and how mere exposure to such residues can impact the environment (European Communities 2008). Food safety assessments and environmental impact studies are essential on a case-by-case basis. Most countries require safety assessments; many require comprehensive risk analyses and the application of precaution in cases of uncertainty. Taking into account the risks and benefits of not using any particular technology in the food system may be the most ethical approach to the introduction of new technologies in food.

Nanotechnology is an emerging technology used in the food industry that affects every aspect of the food system from production to processing, packaging, transportation, shelf life and bioavailability3. Human exposure to nanomaterials is increasing and the health impact of nanomaterials in food is of major public concern (Wallace Hayes and Sahu 2017). Since nanotechnology is a new and rapidly developing technology, very limited information exists about its safety concerns, which raises ethical questions about its use. Currently there are no internationally accepted standard protocols for toxicity testing of nano-materials in food or feed. An international regulatory framework for the evaluation of nanotechnology for both food and animal feed must be established (Wallace Hayes and Sahu 2017).

Uncertainty and the precautionary principle

Contemporary environmental health risks result from complex interactions among new technologies, genetic, nutritional, chemical and environmental and socioeconomic factors.

In areas such as chemical safety, biotechnology or nanotechnology in the food sector, the potential for environmental and health impacts may be great, including the deterioration of ecosystems, the persistence of ubiquitous endocrine-disrupting chemicals, the cross-breeding of genetically modified species or the introduction of nano-particles in human tissues. These practices may be harmful to health directly or indirectly through effects which may be difficult to detect and measure, but with serious consequences, perhaps borne by the most vulnerable or any person, or in the future (Martuzzi 2007). The precautionary principle should be taken into account when there is a risk to health or environmental damage and relevant scientific data are not available, to make sure that all technologies avoid the risk of 'serious or irreversible damage' (UN 1992). The precautionary principle provides a useful means of guiding decisions under conditions of uncertainty, in a manner that appropriately addresses the issues of power, ownership, equity and dignity (WHO 2004).

5.9.3 Food loss, waste and management: ethical considerations

The minimization of food waste and losses during production, post-harvest and processing, as well as marketing and consumption are ethical imperatives (FAO 2014b) (See Section 5.10.3).

The generation and disposal of agricultural waste, and in particular of hazardous waste, can result in negative social impacts (e.g. health risks, noxious odours), environmental pollution (e.g. leaching from inappropriate disposal, gaseous emissions) and economic damage (e.g. cost of disposal and rehabilitation). The food system dominates anthropogenic disruption of the nitrogen cycle by generating excess fixed nitrogen. Excess fixed nitrogen augments the greenhouse effect, diminishes stratospheric ozone, promotes smog, contaminates drinking water, acidifies rain, eutrophicates bays and estuaries and stresses ecosystems (Socolow 1999).

Plastic packaging waste from the food and beverage processing sectors is also a growing environmental health concern. Plastic packaging is the fastest growing form of packaging and only 14 per cent is recycled in the U.S. (MacKerron 2015). The rest ends up in landfills and is a major contributor to ocean pollution. Most plastics currently used to package food are made from petrochemicals and are not biodegradable. Marine plastic litter poses a global challenge, directly affecting marine and coastal life and ecosystems, enters into the food chain representing a risk for human health and future generations. This raises ethical and intergenerational justice considerations. In this context, the EU has been supporting research to develop greener, sustainable alternatives to cut plastic waste and promote biodegradable plastics made from crop waste for use as food packaging, as part of the European Strategy for Plastics in a Circular Economy (EC 2018). The EU has committed to increase recycling target of plastic packaging to 55 per cent and reduce landfill to less than 10 per cent by 2030.

5.9.4 Ethics of food and meat consumption in high-income and middle-income societies

Food choices and consumption behaviour involving purchasing and disposing of food can have ethical significance. The tradeoffs between environmental sustainability and ensuring that individual dietary and nutritional needs are met can be a source of ethical tension (Fanzo 2015).

A common trend in many countries is the shift from plant-based diets to income-dependent diets with high animal source foods such as meats, dairy and other

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3 Bioavailability can be described as the degree to which food nutrients (or nutraceuticals) are available for absorption and utilization in the body.

animal products (Popkin et al. 2012; Tilman and Clarke 2014). There are worldwide inequities in the consumption of animal sourced foods. While the global average for annual consumption of meat is 38 kg/capita, the U.S. consumes 124 kg and countries in Africa and South Asia consume the least amount of meat (between 3 and 5 kg) (Speedy 2003). The increase of meat consumption in high-income and middle-income countries has ethical considerations (Global Food Ethics Project 2015). For example, increased demand for animal source foods and livestock production has implications for climate change, human health, environmental pollution, biodiversity loss and animal welfare (FAO 2006). There are also ethical issues related to the use of food crops to feed animals and for biofuels while global hunger affects more than 800 million people worldwide (FAO 2008). In the near future, such ethical concerns may play an increasing role in affecting the production and consumption of livestock products (Thornton 2010).

5.9.5 Animal welfare and ethics

Animal welfare refers to the physical and psychological well-being of animals. Research into animal behaviour has provided evidence supporting the notion of animal sentience (i.e. animals' capacity to sense and feel), which in turn has provided the basis for EU legislation that integrates the concept of animal sentience into law (Lawrence 2009; Thornton 2010). With this in mind, keeping animals free from hunger, thirst, discomfort, pain, disease and other distress, and providing conditions that they allow them to express their natural behaviour, are considered to be important ethical considerations.

Livestock production is predicted to double in 2050 from present levels, with most of the increase taking place in developing countries where conditions for animal health and welfare raise major ethical concerns. Overcrowding, use of non-adapted breeds, inappropriate use of hormones and drugs, lack of space, clean water and feed, and cruel treatment are common in livestock production systems (FAO 2014b). These and other considerations (e.g. stocking densities) along with slaughtering ethics also relate to fisheries and aquaculture industries.

The EC (2006) and World Organisation for Animal Health (OIE 2017) have adopted standards for the international welfare of domesticated animals and food, which created mandatory animal welfare standards for most foods of animal origin.

5.10 POLICY RESPONSES TO BUILD EQUITABLE FOOD SYSTEMS

Creating an equitable food system requires developing a set of policies geared toward the issues raised in this chapter, namely: improving poor people's access to land, water and other natural resources, ensuring labour rights, improving access for all to new technologies, such as improved seeds and information technology, creating access to local and international markets, and investing in improving gender equality and women's education and status among others (Pinstrup-Andersen et al. 2001; Kessler and Chen 2015).

5.10.1 Healthy, affordable, ethical, fair and sustainable food systems

FAO (2011) proposes that a more equitable, ethics-based, food and agriculture system must incorporate concern for widely accepted global goals, each of which incorporate numerous normative propositions such as improved well-being, improved public health and protection of the environment.

Accessible and affordable healthy diets

Equitable food systems should offer healthy food options that are accessible to and affordable by a community's neediest members. Policies enacted in cities and towns can play an important role in providing access to affordable and healthy food options. For example, CDC (2014) provides strategies and guidance for full-service grocery stores, small stores, farmers' markets, mobile food retailers, and transportation/distribution systems, particularly in underserved areas.

Regulatory policies have been used widely to improve the quality of people's diets. These include, in particular, the regulation of the nutritional information conveyed to consumers on food packages (nutrition labels), the regulation of food advertising (particularly to vulnerable consumers, such as children), and the regulation of the use of particular ingredients in food manufacturing (e.g. industrially produced transfats). There is evidence that consumers use nutrient lists, but label use is considerably lower among people of lower socioeconomic conditions (Sassi et al. 2009). Multi-country modelling studies found that mandatory labelling schemes are effective in countries at different levels of income (Sassi et al. 2009; Cecchini et al. 2010). "Traffic light" labelling[4] was also

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[4] Food may be labelled with a traffic light label showing how much fat, saturated fats, sugar and salt are in that food by using the traffic light

shown to be effective (Sacks et al. 2011) and using a mandatory "tick" symbol to indicate products low in salt, with the expected effect of food companies significantly reducing salt content, was shown to be effective (Cobiac et al. 2010). There is also evidence that food labelling may pressure companies effectively, and lead to reformulation of food contents – e.g. reduction in salt and fat, or increase in fibre (Vyth et al. 2012; Capacci et al. 2012).

Existing studies suggest that regulation of advertising to children (Chou et al. 2008; Magnus et al. 2009), and particularly in fast food (Dhar and Baylis 2011), can have positive outcomes for dietary intake (Veerman et al. 2009). One of these studies compared the cost–effectiveness of restricting commercial promotion through mandatory and self-regulatory approaches in five countries (Sassi 2010; Sassi et al. 2009; Cecchini et al. 2010). Restrictions were highly cost-effective in the 20 years after implementation, especially in low- and middle-income countries, where they may even be cost-saving in some instances. Also, the extension of existing regulations in Australia to include food advertising during specified children's TV viewing hours was found to be a highly cost-effective policy (Magnus et al. 2009).

Ethics and ethical traceability

Equitable food systems should be built around the fundamental values of food ethics from the perspective of both suppliers and the consumers. From the supply end, ethical concerns about animal welfare, production methods, working conditions, terms of trade, impact on the environment, and food safety and security should all be considered comprehensively. These concerns relate in turn to the concepts of trust, voice and transparency (Lang 2010). Ethical traceability is a tool that can be used to keep track of the ethical aspects of food production practices and the conditions under which the food is produced and can apply to all actors in the food chain: suppliers, producers, processors, retailers and consumers. From the demand side, there are ethical considerations related to consumer's unsustainable dietary choices and food waste. There appears to be a gap between the ethically-minded consumers' intentions and their actual behaviour (Carrington et al. 2010). Therefore, understanding how to close the gap between ethical intentions and purchasing decisions will be paramount to protecting food system ethics.

Environmental, social and economic sustainability

Sustainable food systems deliver food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised (HLPE 2014). A sustainable system would feed and nourish the world using the fewest resources possible, while improving the availability, access and utilization of food resources over time. Even more, sustainability in food systems would especially ensure that communities in rural areas of the world will have food security and that they would also control their lands to be used in an efficient way. FAO (2014b) proposes five key principles that balance the social, economic and environmental dimensions of sustainability: i) improving efficiency in the use of resources; i) conserving, protecting and enhancing natural ecosystems; iii) protecting and improving rural livelihoods and social well-being; iv) enhancing the resilience of people, communities and ecosystems; and v) promoting good governance of both natural and human systems. These five principles provide a strong basis for developing equitable and socially just national policies, strategies, programs, regulations and incentives that could guide the transition to an agriculture that is highly productive, economically viable, and environmentally sound.

Equitable and fair trade

In order for the food system to provide opportunities for poverty reduction and shared prosperity, WFTO (2004) recommends that international development policies and initiatives need to:

1. focus on ensuring a sustainable and reliable source of food production in key agriculture-exporting countries;
2. support agricultural development in countries where the poor rely heavily on agriculture for incomes and nutrition; and
3. ensure that food importing countries have social protection systems in place to absorb volatility in international food markets.

Perhaps the most well-known examples of this is the fair trade movement (see **Box 5.8**).

5.10.2 Gender equity and equality

Equitable food systems need to eliminate gender barriers in agriculture and food systems. **Box 5.9** describes a number of areas in which policies could strengthen the rights and participation of women in agriculture.

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signals for high (red), medium (amber) and low (green) percentages for each of these ingredients.

Box 5.8 Fair Trade

The Fair Trade movement is a global initiative with the overarching goal of greater equity in international trade. It began with the initial objective to establish partnerships between the suppliers and consumers of the global North and the smallholder farmers and producers of the global South through Fair Trade Organizations (FTOs) worldwide. This movement aimed to create opportunities for marginalized producers in low-income countries to improve their livelihoods through fair access to export markets.

Fair trade is now an international movement that seeks to provide products that respect not only the people, but also the planet. A guiding set of standards apply to smallholder farmers, workers, and artisans to ensure they get their rightful share of benefits from trade, as well as safe and healthy work environments and adequate housing where appropriate. All products that meet the standards are certified and recognized globally with the FAIRTRADE logo. Fair-trade International also works to guarantee traceability of products. Fair trade offers consumers a direct way to alleviate social inequity by helping disadvantaged communities through purchasing choices.

Box 5.9 Policies to strengthen the rights and participation of women in agriculture (Source FAO 2011; Pehu et al. 2009)

FAO (2011) proposes four key areas in which policies could strengthen the rights and participation of women in agriculture:

> **i) Support women's leadership capacity-building in rural organizations:** Women in developing countries represent 43 per cent of the workforce in agriculture. Improving access to technology and the information to implement those technologies in agriculture, providing climate mitigation and adaptation strategies, and training in marketing, leadership and communication will help build their capacity. To close the gender gap, women need to be educated on policy issues that affect them as farmers and producers. Empowering women with these tools will make smallholder agriculture more sustainable and it will increase productivity overall._
>
> **ii) Improve women's tenure over productive resources such as land and water:** To ensure women's rights to an adequate standard of living it is essential that women have access to productive resources such as land and water. If women are granted the same access to land as men, their productivity can increase 20-30 per cent, which would raise the overall agricultural output in developing countries by 2.5 or up to 4 per cent. This increase in production could potentially decrease hunger in the world by 12-17 per cent (FAO 2011).
>
> **iii) Support women's economic empowerment through training:** This can lead to an increase not in only in their productivity in agriculture, but it can also lead to human capital improvements including better nutrition, education, and health of entire families. Women's economic opportunities can be improved providing training in production techniques, business managements and financial literacy. Granting women equal rights of access to financial services is the first step to reduce the gender gap in this area. Microfinance programs have proven to be effective in overcoming barriers for women in the credit markets. Giving women access to information and legal services is crucial for gender equity especially in terms of land acquisition.
>
> **iv) Improve women's participation in, access to and control in local markets:** Improving women's participation and access to local markets requires program interventions that are based on careful analysis. Women tend to be smallholder farmers who cultivate traditional crops for their own consumption and sale (Pehu et al. 2009). This scenario for women in agriculture and the market place will change if they are granted greater access to own land and to the financial resources they need to increase their productivity and be more competitive. Education and training are important factors in increasing women's presence and impact in the market (Pehu et al. 2009).

5.10.3 Labour rights and equitable food systems

To end child labour, forced labour and slavery will require a multi-sectoral effort to address economic, socio-cultural and legal aspects that contribute to poverty vulnerability and enable exploitation. ILO (2017b) lists a set of overarching policy priorities that can help in these goals, including:

> i) strengthening social protection programs to offset the vulnerabilities that can push children and people into forced labour and slavery;
>
> ii) extending labour rights in the informal economy, where child labour, forced labour and slavery is most likely to occur;
>
> iii) improving migration governance;
>
> iv) addressing the root causes of debt bondage;
>
> v) strengthening and extending national research and data collection efforts on child and forced labour and modern slavery to guide national policy responses; and
>
> vi) encouraging international cooperation among governments and with relevant international and regional organizations to address forced labour modern slavery (given its global and cross-border dimensions).

Areas of cooperation between and among governments should include labour law enforcement, criminal law enforcement and the management of migration in order to prevent trafficking and to address forced labour across borders.

Increasing support for worker organizations and their collaborations with other groups outside of the government can aid capacity building of these groups, enabling them to better resist corporate and industry violations (FAO 2014b). On the international level, workers need to be represented in forums to monitor compliance with agreements to ensure that stronger regulations are put in place and that the global community complies with the norms.

In correcting the labour-related inequities in the food system, reform-minded individuals might consider pursuing two types of strategies: i) removing barriers to the enforcement of existing labour and employment protections; and ii) bolstering and improving existing laws (Lee 2017) (See, for example, **Box 5.10**).

Box 5.10 Box 5.10 Strategies for improving labour enforcement in the U.S. food system

Lee et al. (2017) describe a situation in the U.S., where significant resource constraints on enforcement agencies like the Department of Labour (at the federal level), as well as at similar agencies within the various states, limit their effectiveness. There are many worksites to investigate. Technology might allow agencies to deploy their resources more efficiently, thereby expanding their reach and influence. In recent years, agencies have experimented with technology that enlists the help of consumers in enforcing labour law. The U.S. Department of Labour has utilized both app-based and web-based technology to disseminate information to the public about non-compliant businesses so that consumers can “vote with their dollars”. These technologies enable labour officials to convert a relatively inscrutable inspection into a public spectacle that can be broadcast across popular information-sharing channels, thus encouraging restaurants across the industry to comply with labour requirements or else face the possibility of negative public attention. A larger issue is immigration reform that would include an opportunity for currently unauthorized workers to adjust their status. Enabling workers to obtain formal work authorization strips employers of the removal threat, which would in turn empower workers to enforce labour and employment laws themselves.

Bolstering and improving existing labour and employment laws in the restaurant industry would also help. The most obvious would be to do away with the current tip-based wage system that characterizes the restaurant industry. Rather than allowing restaurant owners to use customer tips to subsidize their wage responsibility, Congress could repeal the tip-based system thus making restaurant owners bear full responsibility for wages and bringing restaurants in line with conventional labour and employment norms. Raising costs for restaurant owners may force some out of business, but the severity of this problem remains understudied. Administrators could take less drastic steps by relaxing the regulations governing tip sharing and thereby close the wage gap separating the front and back of the house. With the right adjustments, tip-sharing policies could allow restaurants to create more equitable norms on the issue of pay.

5.10.4 Education

Knowledge and education can help break the poverty cycle, achieve sustainable food systems, close the gender gap in agriculture productivity and contribute to social equity.

Rural education is key to lifting rural families out of poverty and helping farmers to improve management techniques and reduce negative social and environmental externalities. Initiatives such as Farmer Field Schools (see Box 5.11), which aim to improve education, co-learning and experiential learning so that farmers' expertise is improved, can contribute to sustainable and equitable food systems, for example by providing resilience to current and future challenges in agriculture.

Farmers should be able to produce food that is socially, economically and environmentally responsible and consumers are expected to make informed choices that are conducive to healthy lifestyles (MA 2005). Both goals require building sustainable food consumption and production knowledge systems, improving food literacy policies, promoting domestic food preparation and healthier diets and lifestyles, and furthering knowledge of the benefits of short food supply chains (MA 2005; Vidgen 2016; Kneafsey et al. 2013).

5.10.5 Economic instruments

Food Procurement as an economic development driver

Food procurement can act as an economic development driver that promotes equity. Some of the principles that may contribute to sustainable and equitable food systems include: sourcing food from small-scale producers, guaranteeing living wages and fair prices along the food supply chain, setting specific requirements for adequate food diets to promote healthy lifestyles, sourcing food locally when possible, demanding that suppliers produce food using sustainable practices, designing contracts that will benefit suppliers and ensure that they capture a fair portion of the value, and increasing participation and accountability along the food supply chain (de Schutter 2015).

Ecosystems services payments as a driver to promote equity

Equity and fairness are specific to each group of people who hold similar values. Groups evolve and change over time; so do value systems. Equity can refer to the participation in the decision making process (procedural justice) or to the allocation of outcomes (distributive justice). Both are important, as the former establishes how a Payment for Ecosystem Services (PES) scheme works while the latter focuses on the distribution of benefits and losses. Pascual et al. (2010), argues that different fairness criteria have different implications in PES schemes and offers a useful classification of different economic fairness criteria as presented in **Table 5.3**.

Box 5.11 Farmer Field Schools and social capital

Farming is often a collective business and farmers occasionally form formal groups and structures to sustain their activities over time. Recent approaches such as Farmer Field Schools, participatory irrigation management, watershed management, microcredit groups and joint forest management have increased social capital in agricultural systems and contributed to transformed social equity. These measures are helping to transform some natural resource sectors, such as forest management (e.g. with 25,000 forest protection committees in India), or participatory irrigation (e.g. with 33,000 active groups in Sri Lanka). Nearly two million Asian farmers are engaged in sustainable rice management as a result of Farmer Field School programs (FAO 2018b).

Table 5.3 Fairness criteria for PES programs (Source: Pascual et al. 2010)

Fairness Criterion	Design implications
Compensation	Payments should compensate landholders for the forgone benefits related to the provision of environmental services. Payments are differentiated according to the cost of provision.
Common goods	Payments should be invested in common goods, so all providers' benefit indirectly and according to their relative use of the common goods in question. Payments are not differentiated (no direct payment).
Egalitarian	Design should distribute funds equally among all the providers (per unit of land area, for example), independently of the level and cost of environmental service provision. Payments are not differentiated.
Maxi–min	Payments aim to maximize the net benefit to the poorest landholders, even at a cost of efficiency loss. Payments are differentiated according to the income of providers.
Actual provision	The allocation of funds among landowners corresponds to the actual outcome level of provision of environmental services. Payments are differentiated according to the actual provision of the service.
Expected provision	Payments to landholders depend on the expected level of provision of services for a given land use. Payments are differentiated according to the expected provision of environmental services. These payments compensate landholders to particular land use changes or practices expected to enhance the provision of environmental services.
Status quo	Payments should maintain the previous level of relative distribution of income among providers. Payments are differentiated according to its impact on income inequality.

The fairness criteria adopted by a PES scheme reflects and affects the relative weights given to equity and efficiency concerns within the program. Key research priorities have been identified with regard to the interdependency between efficiency and equity effects in PES programs (Pascual et al. 2010; Muridian et al. 2010), including: i) the need to analyze the potential context-dependent impacts of applying different fairness criteria and the social reasons explaining why a particular criterion prevails over others and how this may change over time (Pascual et al. 2010), ii) the need to take into account the institutional backdrop affecting the power relationships between buyers and sellers of environmental services, and iii) the need to address uncertainty arising from the complex links between ecosystem processes, services and values and how this impacts intermediary coordinating stakeholders' actions. In this regard, close collaboration between ecologists, economists and social scientists needs to be forged.

Taxes on food to promote healthy diets

Taxes on food and non-alcoholic beverages are used in an increasing number of countries to improve the quality of people's dietary choices and encourage healthier eating. The role of taxes as a public health tool has been debated for a long time (e.g. Jacobson and Brownell 2000; Marshall 2000), and taxes have been implemented recently in many jurisdictions, particularly on sugar-sweetened beverages.

Several countries, including the United Kingdom (Smith et al. 2018), Portugal (George 2017), Spain (Ortún et al. 2016), Estonia (Kohler and Reinap 2017) and South Africa (Stacey et al. 2017) announced plans to introduce taxes on sugar-sweetened beverages in 2016. Similar taxes have also been implemented or are being implemented in several US cities (Powell and Maciejewski 2018), Latin American (Nakhimovsky et al. 2016), and Asian countries (WCRF 2017).

The evidence base on the potential effects of taxes on nutrition and health has grown considerably in the past few years. A recent review by Sassi et al. (2013) concluded that taxes have the potential to shift consumer behaviour towards healthier dietary patterns, but the effects depend largely on the details of the policy design. A review of simulate models concluded that taxes on carbonated drinks and saturated fat and subsidies on fruit and vegetables would be associated with beneficial dietary change (Eyles et al. 2012). Detailed analyses of the impact of the tax implemented in Mexico have shown a significant reduction in the consumption of sugar-sweetened beverages and substitution with water, especially in low socio-economic groups (Colchero et al. 2016).

Food subsidies can either be targeted at specific food commodities, or at consumers (in general or selected groups). In the former case, the challenge is to ensure that subsidies effectively translate into reduced market prices; in the latter, that consumers spend the extra money to purchase healthy foods. Studies on the effects of population-level food subsidies, reviewed in Thow et al. (2010), suggest that subsidies influence consumption in the intended direction, and that taxes are more effective when combined with subsidies. Lower prices of fruit and vegetables were found to be associated with lower weight outcomes, especially for children in low-income groups and for those with the highest levels of body mass index (Powell et al. 2013).

The potentially regressive financial effects of food taxes are a source of concern. However, in many low-income countries, a larger proportion of high-income than low-income households purchase foods and non-alcoholic beverages that are typically targeted by those taxes, and even in countries where the opposite is true, the extra burden of taxation borne by low-income households is relatively modest (Zhen et al. 2013).

5.10.6 Good governance

Ensuring equitable and sustainable food systems requires good governance in the social, environmental and economic spheres. For example, environmental issues that affect sustainable food systems and equity include climate change, loss of biodiversity, ocean acidification etc. Economic issues that contribute to inequity include low wages and limited food access; these issues are more dire for populations such as women, poor people and people of colour.

Good governance considers issues of corporate ethics and transparency, increases participation and accountability (holistic audits, responsibility and transparency), considers threats to the rule of law and supports holistic management (FAO 2014a). All of these factors can contribute to sustainability and equity. Decisions concerning the environment, the economy, or social well-being must consider all affected stakeholders.

Precaution is a fundamental element of good governance and it is necessary, either when potential health, environmental or social threats can be far-reaching and irreversible, when technological development evolves fast enough to outpace the accumulation of data, knowledge and evidence, or when the adverse impacts of policies may be felt at great distances, or by future generations (Martuzzi 2007). The precautionary principle serves as a guide for considering uncertainty of the effects of human activities, and provides a framework for protecting humans, other species and life sustaining ecological systems now and in the future (WHO 2004). The precautionary principle is particularly important in transition economies that may have greater environmental, health and equity problems related to food systems; in these countries, economic priorities may outweigh the need to protect health, the environment and social equity (WHO 2004).

5.11 CONCLUSIONS

There are many social equity and social justice aspects (and determinants) that can be affected by different activities of the agri-food system including production, processing, manufacturing, distribution, trade, retail, access, consumption, and waste generation and management. The chapter has identified main components of equitable food systems and existing policies to promote them. Labour rights, working conditions and wages, gender equality, health equity, trade issues are all relevant in agri-food systems.

Ethical considerations related to food systems may range from issues related to human rights, sustainability, new technologies, safety, the roles of corporations, marketing and trade, dietary choices such as increasing meat consumption in high-income and middle-income countries, animal welfare, and the use of crops for energy and animal feed in a world affected by hunger and malnutrition.

More complex food systems can result in increasing unpredictable risk factors and uncertainty, and the use of the precautionary principle can encourage cross-disciplinary problem solving to address complex risks.

The large food requirements projected by the poorest regions in 2030 combined with the damaging impacts that climate change will have in exactly in these regions, disproportionately affecting the most vulnerable farmers it is matter of a critical concern. A key challenge from an equity perspective is to maximize the inclusion of smallholder farmers, women and the youth in the world's food system. These new challenges will come on top of existing challenges such as the gender productivity gap or imbalances in food trade. Equity challenges become more complex due to the accumulated impacts of different factors.

Poverty and malnutrition in all its forms, despite recent progress, should remain a focus of concern. Long-term trends, such as urbanization, means urban poor populations will continue to increase and remain very vulnerable to changes in food prices. At the same time, undernourishment coexists with an obesity crisis (related to growing levels of diabetes, heart diseases and certain cancers) in the world.

Considering the multi-dimensional aspects of social equity is critical to achieving equitable food systems. Policies can promote equitable and ethically-based food systems; to do so they must incorporate widely accepted global goals, each of which incorporate numerous normative propositions such as improved well-being, improved public health and environment. These policies include the promotion of labour rights, gender equality, fair trade, education economic and regulatory mechanisms and good governance in order to promote affordable healthy diets for all and ethical, fair and environmentally and socially sustainable food systems. Labour rights apply to enterprises of all sizes and types (primary production, processing and marketing), as well as all types of ownership structures including cooperatives, single-family businesses, collectives, community-owned land trusts, tribal associations, and corporations. Ethical issues play a key role in building equitable food systems. Other policies that contribute to equitable food systems include advancement of education policies (rural education as well as sustainable consumption policies), incentives through food procurement, payments for ecosystem services using fairness criteria, use of taxes and food subsidies to improve the quality of people´s dietary choices and regulatory mechanisms.

A comprehensive approach to reducing health inequities related to food systems, such as inequities in obesity, involves a combination of policies that address inequities in the root social determinant, as well as policies that treat the symptoms or attempt to compensate for inequities in the social determinants of health.

Good governance in the social, environmental and economic spheres is in the realm of equitable and sustainable food systems.

Social equity, justice and ethical considerations should be fundamental values underlying sustainable food systems. Social equity is a critical component of most SDGs, which will likely drive development policies for the next 15 years and it is critical they are achieved with equity in mind. TEEBAgriFood suggests using a three-tiered structure for the 17 SDGs, emphasizing how our planet's natural resources underpin delivery of the 2030 Agenda. This means that the SDGs should be implemented in an integrated manner and that equity should be seen as a crosscutting issue. The TEEBAgriFood Framework offers an approach to assess the cost and benefits of the impacts of food systems on different aspects of social equity considering all the components, institutions and policies of the food system, from the production and processing phases, trade to access and consumption including food waste management. In this context, the TEEBAgriFood Framework could provide a means by which information and data on social equity related to food systems can be collected and organized to assess progress towards the SDGs.

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CHAPTER 6

THE TEEBAGRIFOOD FRAMEWORK: TOWARDS COMPREHENSIVE EVALUATION OF ECO-AGRI-FOOD SYSTEMS

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SUMMARY

Chapter 6 presents the TEEBAgriFood Evaluation Framework. The Framework establishes "what should be evaluated" and represents the next generation in assessment tools for eco-agri-food systems. It supports the assessment of different eco-agri-food systems, covering their human, social, economic, and environmental dimensions, from production through to consumption. The common, production-only, focus of assessment, using for example metrics of yield per hectare, ignores the significant range of social and environmental impacts that must be included for a complete evaluation. The Framework applies a multiple-capitals based approach, and supports the use of monetary and non-monetary approaches to impact assessment, including value-addition. As a comprehensive and universal framework, it highlights all relevant dimensions, and drives policymakers, researchers, and businesses to broaden their information set for decision-making.

CONTENTS

FIGURES, BOXES AND TABLES

CHAPTER 6

6.0 KEY MESSAGES

- This chapter presents a framework that supports the evaluation of different eco-agri-food systems, covering their human, social, economic, and environmental dimensions, from production through to consumption.
- Common assessment metrics, such as yield per hectare, ignore a wide and significant range of social, human, and environmental costs and benefits of eco-agri-food systems.
- The primary goal of the TEEB-Agri-Food Evaluation Framework is to support decision-makers in establishing "what should be evaluated" in a given assessment, and consequently, to bring transparency and context to all assessments, by highlighting elements which may have been overlooked.
- The Framework systematically categorizes all elements – including human, social, economic, and environmental stocks, flows, outcomes and impacts - which could potentially be described and analyzed in an assessment of eco-agri-food systems.
- The Framework has been developed with three guiding principles:
    1. universality: providing a common language in all decision-making contexts;
    2. comprehensiveness: including all relevant social, environmental, human, and economic elements along the entire value chain;
    3. inclusiveness: supporting multiple approaches to evaluation and assessment including in both qualitative and quantitative terms.
- The Framework is designed to support (a) the description of the structure and trends in eco-agri-food systems and hence underpin the derivation of indicators and metrics to better understand issues such as capacity, sustainability, productivity and efficiency; and (b) the analysis of eco-agri-food systems using various tools such as cost-benefit analyses, integrated profit and loss statements, ecosystem services valuation, and measures of inclusive wealth.
- The Framework adopts a multiple capitals approach recognizing that eco-agri-food systems, from the production to the consumption stages, are sustained by – and impact upon – all four types of capital: human, produced, social, and natural. A holistic assessment should include all pathways by which eco-agri-food systems interact with these capital bases.
- Eco-agri-food systems are dynamic, with their elements changing and influencing each other over varying spatial and temporal scales; any assessment needs to account for these dynamics.
- The extent of exposure to risk and the degree of resilience of an eco-agri-food system are important considerations for any assessment.
- The range of qualitative and quantitative information needed in order to provide a complete description of an eco-agri-food system cannot be simply aggregated; and, in analysis, care must be taken in selecting relevant variables for each decision-making context.
- The Framework is intended for use in an interdisciplinary manner, where the questions to be analysed, the options to be compared, and the scale, scope, and relevant variables included are determined in an open and participatory way, before the appropriate assessment and valuation methods are implemented.

CHAPTER 6

THE TEEBAGRIFOOD FRAMEWORK: TOWARDS COMPREHENSIVE EVALUATION OF ECO-AGRI-FOOD SYSTEMS

6.1 INTRODUCTION

TEEBAgriFood seeks to evaluate all significant externalities related to eco-agri-food systems. As explored in Chapters 1 and 2, the term externalities refer to the impacts of business on the natural environment – the effects of which tend not to be reflected in the market prices of associated financial transactions, and hence may be "invisible" to decision makers. An 'eco-agri-food' system rests at the nexus of the three systems (economic, ecological and climatic, and social) that are variously involved in growing, processing, distributing and consuming food. Chapter 2 demonstrates that eco-agri-food systems are dynamic and complex with many parts interacting at varying spatial and temporal scales, across economic, environmental and social dimensions. Moreover, crops, production systems and supply chains each have their own set of inputs, environmental and social contexts, policy drivers, and create a wide range of visible and invisible, positive and negative impacts.

Given the heterogeneity and complexity of eco-agri-food systems, simple economic performance measures such as yields per hectare, value-added or profit offer a convenient but incomplete means to compare and rank production systems. Such measures do not take account of complex value chains or environmental and social relationships, even though these relationships are often significant and consequential to human well-being. Excluding them from the information base used to support decision-making can lead to disastrous effects on ecosystems, human health and well-being, as described in previous chapters; and overlooking such factors can also ultimately undermine the sustainability of agricultural incomes and productivity.

This chapter presents a novel Framework to support comprehensive evaluations of eco-agri-food systems, covering environmental, economic and social dimensions, and both positive and negative impacts. We begin by defining the stocks, flows, outcomes and impacts of eco-agri-food systems. The stocks of eco-agri-food systems comprise four different "capitals" – produced capital, natural capital, human capital and social capital. These stocks underpin a variety of flows encompassing production and consumption activity, ecosystem services, purchased inputs and residual flows. The dynamics of an eco-agri-food system lead to outcomes that are reflected in the Framework as changes in the quantity and quality of the stocks. In turn, these outcomes will have impacts on human well-being.

We outline the connections between these elements, as reflected in accounting-based measurement Frameworks, and consistent with the systems theory described in Chapter 2. Collectively, these four elements can be used to describe eco-agri-food systems and to analyse associated impacts on the environment and human well-being.

By providing key definitions and associated measurement concepts and boundaries, the TEEBAgriFood Evaluation Framework establishes what aspects of eco-agri-food systems may be included within a holistic evaluation. This chapter does not focus on how assessments should be undertaken, nor does it prescribe methods for assessments. The choice of methods will depend on the focus and purpose of any given assessment, availability of data, and scope of analysis. Practical guidance and examples of how these and other factors affect the selection of methods are provided in Chapters 7 and 8, respectively.

We hope the Framework presented in this chapter will also orient future interdisciplinary research, providing a starting point for testing and conceptual development. Indeed, given the very broad coverage of the Framework, this chapter cannot describe all aspects of measurement that may be required in every situation. At the same time, this chapter demonstrates the potential to integrate and build on existing Frameworks to provide a basis for the next generation of measurement and analysis. Thus, the chapter provides a step towards the presentation of a holistic picture of eco-agri-food systems, so that future assessments can better inform and improve decision-making.

The chapter is organized as follows: Section 6.2 highlights the role of a common evaluation framework, presents the key principles and broad structure of the TEEBAgriFood Evaluation Framework, and summarizes previous related initiatives. Section 6.3 describes the elements of the Framework and discusses measurement boundaries and linkages. Section 6.4 discusses how the Framework may be applied, including possible entry points for evaluations, how temporal and spatial aspects can be taken into account, and links to assessing the risk and resilience of eco-agri-food systems. Section 6.5 concludes the chapter and sets the scene for a discussion of methods and applications in the following chapters.

6.2 RATIONALE AND GUIDING PRINCIPLES OF THE TEEBAGRIFOOD EVALUATION FRAMEWORK

6.2.1 Rationale for the Evaluation Framework

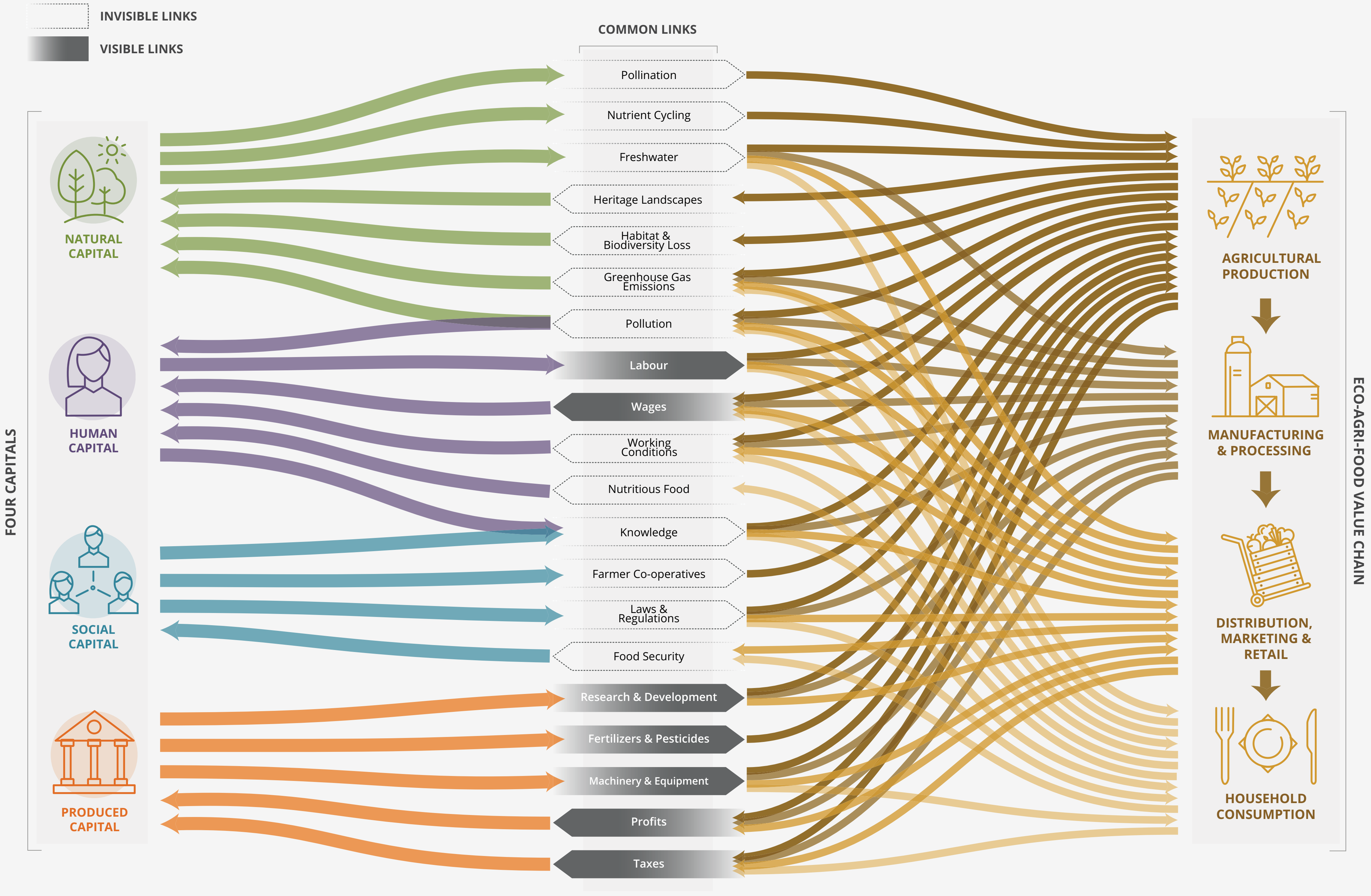
The earlier chapters have amply illustrated the “hidden” or “invisible” costs and benefits in the way we produce, process, distribute, and consume food. These invisible costs and benefits are rarely captured in conventional economic analyses, which usually focus on the production and consumption of goods and services that are traded in markets. For eco-agri-food systems, this approach does not account for a wide array of vital inputs and outputs (see Figure 6.1 below). From an environmental perspective, recognition of ecological inputs to agriculture (i.e. dependencies), such as freshwater provisioning, nutrient cycling, climate regulation, and pollination (MA 2005) are often lacking. Similarly, key outputs of eco-agri-food systems central to human health and well-being, such as impacts on food security, water quality, food safety and local communities, are often unaccounted for (TEEB 2015b). Perhaps most significantly, conventional assessment systems do not effectively capture the changing capacity of ecosystems and supporting social systems to continue to deliver these critical goods and services over the long run.

Figure 6.1 presents the four capitals on the left hand side as the building blocks of the eco-agri-food value chain from production to consumption on the right hand side. The capitals and the value chain are connected through a wide variety of flows to and from both sides. Those flows that are most commonly included in assessments – the visible flows – are shown distinctly from those that are most commonly excluded – the invisible flows – as just described. There is no doubt that the figure, particularly at first glance, is complex, but this is the reality of eco-agri-food systems. A key motivation for the Framework is to provide a means to recognise and engage with this complexity and hence support assessments that are more context specific and meaningful.

TEEB, in its early work, highlighted the implications of the economic invisibility of nature in decision-making, and shed light on the sizeable contributions of biodiversity and ecosystem services to social and economic well-being (TEEB 2010a; 2010b). Extending this environmental-economic perspective, the TEEBAgriFood Evaluation Framework seeks to consider other hidden stocks and flows, including impacts on human health and social equity.

In order to improve and secure our eco-agri-food systems and, in particular, to mitigate their negative impacts, all stakeholders including governments, businesses, farmers and citizens, need to be made more aware of the wider benefits and costs associated with different eco-agri-food systems. Providing analysis and raising awareness are of course only part of the process of improving production and consumptions patterns, which also requires technical innovation, policy reform and behaviour change in order to overcome political and other barriers to change, as discussed in Chapters 9 and 10.

Figure 6.1 Links between four capitals and the eco-agri-food value chain (Source: authors)



Box 6.1 Demonstrating the scope of a comprehensive assessment

To demonstrate some of the considerations that may be included in a comprehensive assessment of eco-agri-food systems, consider a simple palm oil value chain as an example. The following diagram shows the planting and production of palm oil in Indonesia, export of crude palm oil (CPO) to India[1], and subsequent processing, transportation and refinement to refined, deodorized and bleached (RDB) palm oil, through to final consumption in India.

Figure 6.2 Palm oil value chain (source: authors)

In design

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[1] Note that this diagram illustrates just one value chain involving Indonesia and India. For instance, there is also considerable processing and export of RDB palm oil (from CPO) in Indonesia; these production choices are strongly influenced by differential tariff rates between Indonesia and India for these varieties of processed palm oil (see GIST Advisory and Global Canopy Program (2014).

Several points are worthy of note:

1. The system has many parts – a value chain, which includes, for the sake of simplicity, land preparation for growing the fruit, planting, growth, harvest, transport, processing, distribution, and consumption. Other upstream activities, which are also part of the value chain, such as manufacturing of fertilizers, research and development for palm oil, marketing and branding, etc., are excluded here.

2. There are several flows that act as inputs to the value chain – labour, fertilizers, knowledge, and ecosystem services such as freshwater and pollination. There are also several outflows along the value chain – for instance, food and agricultural products and associated incomes, atmospheric emissions, and excess fertilizer in runoff.

3. These flows can lead to several outcomes – for example, farming incomes support rural households financially, emissions such as suspended particulates in smoke from land clearing can lead to negative health outcomes, while fertilizer in runoff can lead to adverse environmental outcomes such as eutrophication.

4. These outcomes also have associated negative or positive impacts, defined as changes in human well-being. For example, eutrophication can negatively impact fish stocks and hence the livelihoods of artisanal fisherfolk; farm incomes can positively impact human well-being for farmers and farm labourers; and health outcomes of emissions can negatively impact labour productivity and quality of life for people both near and far.

5. These outcomes vary in nature. For example, they can be economic (income for labourers; profits for farmers), social (working conditions (ILO 2013), access of women to land and 0ther resources), health related (respiratory diseases from emissions), or environmental (deforestation; eutrophication; etc.).

6. The diagram incorporates elements that are categorically different – i.e. stocks and flows. For example, while on-farm employees are considered a stock of human capital, the ongoing inputs into the production processes (i.e. labour services) are flows.

7. There is a relationship between the quality and quantity stocks and their respective flows – ecosystem services such as freshwater depend on the quantity and quality of upstream forests (“natural capital”), the labour and knowledge that go into the production process depend on the skills and health (“human capital”) of people who work on the plantation, and the condition of processing plants and machinery (“produced capital”) is vital to processing the fruit. Understanding the changing composition and condition of these various stocks and the implications for future flows is a key aspect of the Framework.

8. There is both a spatial and temporal dimension to these flows – for example, flows of ecosystem services such as water and pollination are generated beyond the farm, at a watershed level, over different seasonal or multi-year cycles. Similarly, palm oil produced in Indonesia travels a significant distance to reach the final consumers in India.

9. Lastly, while several of these considerations are made visible in market transactions, many are invisible and are not incorporated in observed prices and values. For example, while incomes and consumption outcomes of a particular production system are made visible by being captured by GDP, the spread of these outcomes across gender and social classes are not. Similarly, while inputs of ecosystem services can be indirectly captured by yields and reflected as income, current yield measures do not reflect the capacity of ecosystems to deliver these services into the future, which is arguably an important measure of sustainability.

To undertake a comprehensive assessment of a palm oil system, all of the factors mentioned above should be considered.

We identify three fundamental requirements of a TEEBAgriFood Evaluation Framework. First, the Framework must identify and characterize all relevant elements of a system. Second, the Framework should provide a common language relevant to all stakeholders. Lastly, the Framework should enable stakeholders to bring together these disparate elements in an integrated analysis for informed decision-making.

With these requirements in mind, the design of the Framework is aspirational, and its operationalization will require testing and ongoing development. The aspirational intent is nonetheless grounded in the application and integration of existing theory and concepts, many of which have been put into practice. In this context, the Framework should be considered as the "next generation" of framework for the evaluation of eco-agri-food systems.

6.2.2 Guiding principles

The three requirements for the design of the Framework underpin the guiding principles of the TEEBAgriFood Evaluation Framework, namely universality, comprehensiveness and inclusivity. These principles are summarized here building on the descriptions in TEEB (2015a).

The first guiding principle is **universality**: no matter the entry point or application, the same Framework can be used for assessing any eco-agri-food system, and can be used equally by policymakers, businesses, producers and citizens. While each assessment may be different in scope and methods, to assure completeness within - and comparability across - assessments, it is important that the *elements* considered and evaluated in each assessment are defined and described in a consistent manner. Failing that, it will not be possible to draw conclusions from comparisons across different scenarios or strategies, since each assessment would be using its own lexicon and definitions. This is precisely why we need a *universal* framework, which consistently and clearly answers the question: *"What should be evaluated?"*

The principle of universality stands in contrast to the current model of siloed assessments, wherein each assessment of a particular eco-agri-food system includes an independently determined set of economic, environmental and social variables, evaluated using different methods which then provide, unsurprisingly, non-comparable results. For example, silo assessments may include assessing agricultural systems solely on the basis of yield per hectare, or efficiency in the use of water or energy, leaving out broader issues of sustainability or equity, which are related to yield and efficiency concerns, but encompass other considerations.

These silo effects become even more distinct across different eco-agri-food systems, for example, when comparing the production and consumption of substitutable outputs, such as types of edible oils. In this example, the Framework should allow for comparison between a small-scale peanut oil production system with a broad-scale palm oil production system. To ensure universality, our Framework is designed to be adaptable to various applications, entry points and pathways of analyses; and the principle of universality requires that different systems can be compared using a single frame of analysis. These elements are further discussed in Section 6.4.

The second guiding principle of our Framework is **comprehensiveness**: both in terms of encompassing the entire value chain, and in terms of including all stocks, flows, outcomes and impacts within an eco-agri-food system. A comprehensive framework ensures that all hidden costs and benefits, including dependencies and impacts upstream and downstream, are part of each assessment over the entire eco-agri-food value chain, covering all aspects of production and consumption.

By way of example, various natural capital inputs to farming such as freshwater, climate regulation and pollination come from beyond the "farm gate", likely at the watershed or landscape scale. Similarly, some hidden costs of farming may occur downstream of the farm gate, for instance, the effects of runoff from excess use of fertilizers. Analyses limited to the agricultural area of a farm may be appealingly simple, but they are also partial and potentially misleading.

Furthermore, value chains for agricultural commodities can differ substantially for the same commodity and such differences will imply different economic, environmental, health and social outcomes and impacts for different types of eco-agri-food systems. For example, corn produced for human consumption has different outcomes for human health compared to corn produced for ethanol or animal feed.

A comprehensive assessment also implies that systems are assessed in terms of observed economic, environmental and social flows, such as production, consumption, ecosystem services, pollution and social benefits, and in terms of the underlying capital base that both sustains the system and can be impacted by the activities within the system. The capital base considered in the TEEB Evaluation Framework is comprehensive, covering produced capital, natural capital, human capital and social capital.

The third guiding principle that flows from universality and comprehensiveness, particularly with respect to the inclusion of social capital, is that the Framework must be **inclusive** in supporting multiple approaches to assessment, including in quantitative and qualitative terms. The evaluation of impacts in the TEEB Evaluation Framework stems primarily from an economic perspective and the accounting-based nature of the Framework directly supports analysis in line with economic theory and the valuation of impacts on human well-being in monetary terms. However, while many flows and stocks can be measured in monetary terms, this is not possible for all aspects of human well-being. Indeed, in different contexts, monetary valuation may not be possible or ethically appropriate, and measurement in qualitative, physical, or non-monetary terms may provide important insights (Pascual *et al.* 2017). Thus, the Framework should allow for a plurality of value perspectives and assessment techniques, such as multi-criteria analysis (See Chapter 7).

Furthermore, while the Framework is designed to support economic analysis, it can also provide relevant data and indicators to support more informed decision making. For example, the Framework design supports the estimation of carbon and water footprints, life cycle analysis, measurement of social equity, and the development of sustainability metrics and indicator sets. The principle of inclusiveness thus extends to developing a common information base that underpins not only economic analysis but also other associated lines of measurement and inquiry.

6.2.3 Relationship to other frameworks

The TEEBAgriFood Evaluation Framework presented in this chapter flows from these guiding principles. Viewed from the perspective of human wellbeing, the Evaluation Framework encompasses a broad range of economic, environmental, health and social outcomes and impacts. Securing these outcomes is related directly to the stock of all forms of capital – produced, natural, human and social. The Evaluation Framework thus posits that the delivery of current human well-being and the capacity to sustain and improve well-being for future generations is predicated on our ability to maintain and enhance the stock of all capitals.

The inclusion of all types of capital and the use of a standard analytical approach in the Framework builds directly on the ongoing work to measure the overall wealth of countries and their genuine savings when it comes to produced, natural, human and social capital (see, for example, Arrow *et al.* 2013; UNU-IHDP and UNEP 2014; IISD 2016; Lange *et al.* 2018). These wealth accounting-based approaches provide a clear economic rationale for the consideration of all types of capital in providing a holistic assessment.

At the same time, the Framework goes further in encouraging the application of wealth accounting at different spatial scales and for specific and potentially globally connected eco-agri-food systems, distinct from the common focus of wealth accounting on national wealth. The Framework also more explicitly recognizes the differences between stocks, and the associated flows and outcomes since, in practice, these are often measured in separate ways rather than in the fully integrated manner envisaged in wealth accounting theory. Finally, the Framework aims to go beyond the productive, economic focus of wealth accounting to encompass other considerations, such as equity.

Within this broad capital accounting framing, the Framework utilizes the rich body of work on measurement reflected in established international statistical standards. In relation to produced and natural capital and associated flows these standards include[2]:

- The System of National Accounts (SNA) and the Balance of Payments (BoP) (EC *et al.* 2009) for the measurement of produced assets (including financial assets and liabilities) and associated flows of production, income and consumption.

- The System of Environmental-Economic Accounting (SEEA) Central Framework (UN *et al.* 2014a) for the measurement of environmental flows (e.g. water, energy, emissions, etc.) and environmental assets (e.g. land, soil, timber, fish)

- The SEEA Experimental Ecosystem Accounting (UN *et al.* 2014b) for the measurement of ecosystem assets, ecosystem services and biodiversity.

- The SEEA Agriculture, Forestry and Fisheries (FAO and UN 2018) for the measurement of environmental assets and flows in the context of agricultural activity (e.g., energy, water, nutrients, emissions, land and soil).

Incorporating a comprehensive natural capital base that includes biodiversity and ecosystem services puts the TEEBAgriFood Evaluation Framework in line with other initiatives such as the Millennium Ecosystem Assessment (MA 2005) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES 2018). Consistent with these initiatives, the Framework recognises the importance of the spatial dimension so that the Framework has relevance from the farm level to the global level and, at the same time, reflects the reality that system-elements will vary from location to location and from system to system.

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[2] Note that in these statistical standards the term "asset" is applied in relation to the measurement of produced and natural capital. In a national accounting context, the term "asset" embodies the concepts of both "stock" and "capital" that are commonly distinguished in the wealth accounting literature.

Other factors such as human capital, social capital and wellbeing are also being better assessed by a number of initiatives, most notably by the OECD (Healy and Côté 2001; Keeley 2007). As for wealth accounting, the focus of work in this area is commonly on national level assessment or for particular population groups. The consideration of finer spatial dimensions or for specific activities and sectors is not apparent at this stage.

In the very broad area of sustainability measurement, both at national and local scales, and for the agricultural sector specifically, there is a broad array of tools, composite indicators and sets of indicators (Reytar *et al.* 2014; FAO 2014; The Keystone Policy Center 2018; People 4 Earth 2018). Although they are commonly motivated to provide a richer picture of progress and sustainability, and in many cases, there is considerable overlap in the themes that are included in any assessment, there is no agreed, underlying framework for integration and there is no standardisation that supports comparison. At a sector level, such as agriculture, sustainability metrics (while usually covering the three primary dimensions of economy, environment and society) are selected from a production perspective and do not encompass the corresponding sustainability of food consumption. This extension is perhaps the most fundamental difference between the TEEBAgriFood approach and other related approaches.

The UN Sustainable Development Goals (SDGs) (UN 2015), which provide an overarching, internationally agreed and universal set of themes and alignment of indicators within this framing, represent a potential step forward. However, there is no underlying conceptual framework that links the 17 goals and 169 targets together. While food production (SDG 2) and health outcomes (SDG 3) are front and centre in the SDGs, the linkages between them have not been broadly articulated, in concept or in practice.

In economic analysis, the application of the general principles of measuring social costs and benefits in relation to agricultural activity are well established. Indeed, chapter 7 demonstrates that the methods to apply the TEEBAgriFood Framework can in large part be drawn from the literature and experience of valuing externalities. There is a limitation in valuation of some social aspects, including social equity, but the general point holds.

What makes the TEEBAgriFood Evaluation Framework distinct is its ambition to incorporate all externalities. As demonstrated in Chapter 8, there are no instances of studies that capture all of the elements of the TEEBAgriFood Framework. In part, this may reflect data limitations but in larger part it reflects the lack of application of a sufficiently broad and systemic perspective on eco-agri-food systems. The TEEBAgriFood Framework thus seeks to encourage more ambitious assessments using the full gamut of economic analysis tools.

The TEEBAgriFood Framework also builds upon the recent momentum in the private sector concerning the disclosure of externalities. As more companies and corporations capture and make such information available, this can support development of, for example integrated profit and loss (IP&L) statements (GIST Advisory 2018) that describe the net economic, environmental and social impact of a business. The original TEEB for Business report (TEEB 2012) highlighted the various environmental risks and opportunities that businesses should address in a resource constrained future, and how businesses can measure, value and report their impacts and dependencies on biodiversity and ecosystem services. Several other works and initiatives such as the WBCSD (2011) Guide to Corporate Ecosystem Valuation, 4-D reporting (GIST Advisory 2018), the NCC (2016a) Natural Capital Protocol (NCP), the Integrated Reporting (IR) framework of IIRC (2013) and the Global Reporting Initiative (GRI 2018) have highlighted the need for better measurement and disclosure of the environmental and social impacts of companies.

The NCP in particular includes a sector guide for food and beverage businesses (NCC 2016b) that provides a more specific guidance in understanding the links of this sector to natural capital. The TEEBAgriFood Evaluation Framework goes a step further by spelling out in more detail the elements that require assessment with respect to natural capital, and the analytical approach to be used in an assessment. In this sense, the TEEBAgriFood Framework can be a complementary tool for companies applying the NCP in the food and beverage sector.

Indeed, the TEEBAgriFood Framework should be seen as complementary to the wide variety of related frameworks and tools. The TEEBAgriFood Framework builds upon existing knowledge and it can provide an evidence base that supports a more comprehensive, systemic and standardised analysis of eco-agri-food systems. It thus represents the next generation of evaluation frameworks. Clearly these goals are ambitious, and data to populate all elements of the TEEBAgriFood Framework for all eco-agri-food systems is not yet available. However, what the Framework does demonstrate is that the wide range of information that is available on the majority of the elements of the eco-agri-food system can be placed in context to support a comprehensive and meaningful assessment of the impacts of the system on sustainability and human well-being.

Notwithstanding the inclusive scope of the TEEBAgriFood Framework, the focus of analysis is on human well-being and hence the Framework reflects an inherent anthropocentric perspective. Thus, the impacts of production and consumption on the 'intrinsic' value of the natural environment, i.e., its value purely as the environment without regard to human connection and use, are not the focus of analysis. For example, the analysis of biodiversity within the Framework focuses on the ways in which biodiversity supports economic activity and contributes to individual and social wellbeing but does not consider the maintenance and enhancement of biodiversity as a benefit for the environment itself. At the same time, as presented in the following section, the Evaluation Framework has a descriptive component and thus there is the potential to record non-monetary information on changes in natural capital. Such information may help to underpin discussion of the intrinsic values of nature.

6.3 TEEBAGRIFOOD EVALUATION FRAMEWORK

6.3.1 Conceptual basis for the Framework

The TEEBAgriFood Evaluation Framework defines the four elements - **stocks, flows, outcomes** and **impacts -** that support a standardised evaluation of eco-agri-food systems. In providing these definitions and associated measurement concepts and boundaries, the Framework establishes *what* aspects of eco-agri-food systems should be included within a comprehensive evaluation or assessment.

The Framework is designed for use in two complementary but different ways. First, it can be used to describe eco-agri-food systems to ensure that different stakeholders involved – from farmers and manufacturers, to consumers and local communities – have a common understanding of where they are within the system and how that system is functioning. Without a common language to describe eco-agri-food systems, there is limited potential to achieve the integrated, cross-sectoral decision-making that is required. The descriptive use of the Evaluation Framework incorporates the selection and derivation of relevant indicators and metrics to monitor progress with regard to sustainability. For example, metrics might include the composition of production and consumption of an eco-agri-food system, its geographical scope, the components of the value chain and changes in these elements over time. In this respect, the Framework is intended to bring transparency and context to all assessments of agriculture and food systems, and can be used to highlight elements that may have been omitted from an assessment.

Second, the Framework can be used to support various forms of analysis. For example, the Framework supports the assessment and comparison of trade-offs from agricultural and food policies, analysis of land use and consumption choices, and consideration of decisions concerning public and private investments. The ultimate focus of analysis in the Framework is on impacts to human well-being. Impacts are also referred to as "value-additions" as per the TEEBAgriFood interim report. Methods for estimating the relative value of these impacts are discussed in chapter 7, including techniques for the assessment of social impacts.

Figure 6.3 shows the core structure of the Framework and its elements. The descriptive use of the Framework will tend to focus on stocks, flows and outcomes. The analytical use of the Framework will tend to focus on outcomes and the impacts of eco-agri-food systems on human well-being. In both uses there is intended to be coverage across all stages of the eco-agri-food value chain, from production through to final consumption and human health. Additionally, the Framework supports assessment across multiple spatial scales, from the local farm level to global supply chains. Section 6.4 describes steps towards implementation of the Framework.

As presented, the Framework may appear to be relatively linear. In fact, there are many and varied connections between the elements of the Framework that cannot be fully described here. The logic for considering these connections is described in Chapter 2, which discusses a systems approach to analysis of the eco-agri-food system. In effect, **Figure 6.3** provides an abstraction of the complexity of any given eco-agri-food system to provide a common starting point for the understanding of each system. While all of the potential connections are not illustrated, special note is made of the link between outcomes and stocks. Outcomes are defined to reflect changes in the extent or condition of stocks (in quantitative and qualitative terms) that arise due to value chain activities. This connection is a key dynamic within the Framework. These changes in stock, recorded as outcomes, reflect changes the capacity of the stock to generate flows of services and hence underpin the ongoing generation of well-being.[3]

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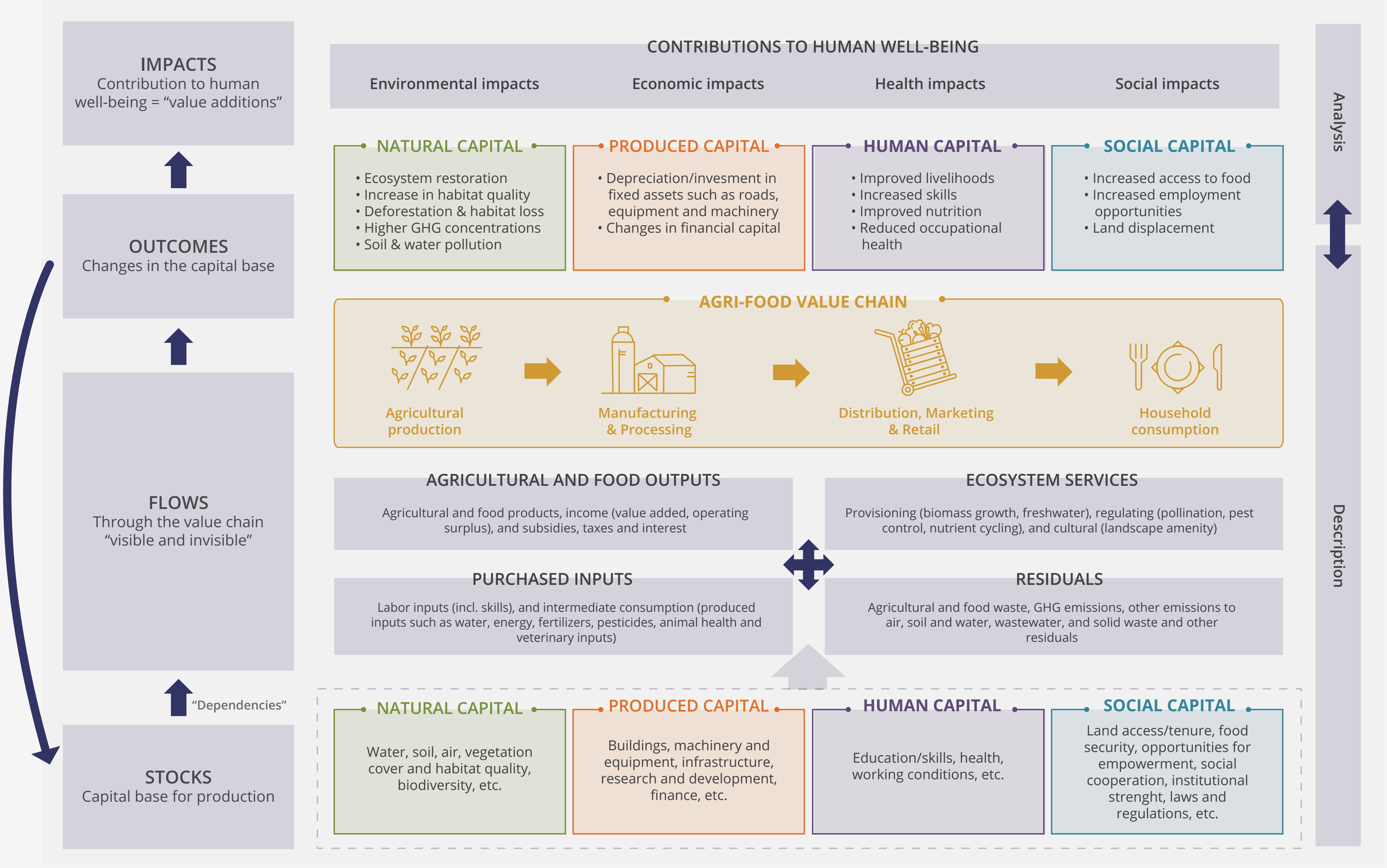
[3] In the discussion of the linkages between stocks, flows, outcomes and impacts a range of terms are applied in different ways by the different subject matter experts who have considered these issues. In particular, differences can emerge in the use of the words "stock", "asset" and "capital". In this study, the word "stock" is used in relation to the physical or observable quantities and qualities that underpin various flows within the system. Stocks are classified as being produced, natural, human or social. The word "capital" is used to reflect the economic perspective of the various stocks in which each type of capital embodies future streams of benefits that contribute to human well-being. The word "asset" is not used. While it is clear that there are differences in the use of terms among experts, the authors are satisfied that the conceptual intentions are well aligned.

Figure 6.3 Elements of the TEEBAgriFood Evaluation Framework (source: authors)



IMPACTS
Contribution to human well-being = “value additions”

OUTCOMES
Changes in the capital base

FLOWS
Through the value chain “visible and invisible”

“Dependencies”

STOCKS
Capital base for production

CONTRIBUTIONS TO HUMAN WELL-BEING
Environmental impacts
Economic impacts
Health impacts
Social impacts

NATURAL CAPITAL
- Ecosystem restoration
- Increase in habitat quality
- Deforestation & habitat loss
- Higher GHG concentrations
- Soil & water pollution

PRODUCED CAPITAL
- Depreciation/invesment in fixed assets such as roads, equipment and machinery
- Changes in financial capital

HUMAN CAPITAL
- Improved livelihoods
- Increased skills
- Improved nutrition
- Reduced occupational health

SOCIAL CAPITAL
- Increased access to food
- Increased employment opportunities
- Land displacement

AGRI-FOOD VALUE CHAIN
Agricultural production
Manufacturing & Processing
Distribution, Marketing & Retail
Household consumption

AGRICULTURAL AND FOOD OUTPUTS
Agricultural and food products, income (value added, operating surplus), and subsidies, taxes and interest

ECOSYSTEM SERVICES
Provisioning (biomass growth, freshwater), regulating (pollination, pest control, nutrient cycling), and cultural (landscape amenity)

PURCHASED INPUTS
Labor inputs (incl. skills), and intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health and veterinary inputs)

RESIDUALS
Agricultural and food waste, GHG emissions, other emissions to air, soil and water, wastewater, and solid waste and other residuals

NATURAL CAPITAL
Water, soil, air, vegetation cover and habitat quality, biodiversity, etc.

PRODUCED CAPITAL
Buildings, machinery and equipment, infrastructure, research and development, finance, etc.

HUMAN CAPITAL
Education/skills, health, working conditions, etc.

SOCIAL CAPITAL
Land access/tenure, food security, opportunities for empowerment, social cooperation, institutional strenght, laws and regulations, etc.

Box 6.2 Applying the Framework to assess the palm oil value chain

To illustrate the key elements of the Framework, we revisit the stylised palm oil value chain presented earlier in **Box 6.1**.

Figure 6.4 Palm oil value chain revisited (Source: authors)

In design

The right side of the schematic (A. Production at the farm) describes the various stocks, flows, outcomes, and impacts occurring at the production level. Agricultural land and forest land are two types of ecosystems that are included as natural capital in the Framework. They deliver flows of nutrients, pollinators and water, among many other services. Other capital inputs such as labour (human capital), and machinery (produced capital) contribute to palm oil yields (agricultural and food production and consumption).

Yields contribute to income, which in turn has positive implications for investments in both produced capital such as machinery (a produced capital outcome), but also human capital, in the form of education (a human capital outcome). Some of the negative flows impacting stocks are also demonstrated – e.g. residual flows of emissions and pollutants from land clearing, which can degrade natural capital through biodiversity loss (a natural capital outcome), and reduce human capital through increasing the incidence of respiratory disease (a human capital outcome). An impact of these various outcomes would be the loss in labour productivity; another would be the loss of life quality for farm workers' families due to respiratory diseases.

Produced capital inputs such as oil mills, ports, and ships, allow for exporting palm oil for further processing and final distribution (B. processing and consumption). While consumption of palm oil can support nutrition and general food security, excess consumption can lead to obesity as a health outcome, which in turn can lead to loss in human well-being. This negatively affects human capital and can have secondary impacts on labour inputs for other sectors.

The systematic framing of the various elements as shown in the palm oil example (**Box 6.2**) allows for comparison between, for instance, traditional palm oil systems and certified sustainable palm oil systems. The Framework supports comparable assessments of the relative impacts on human well-being, extending the focus beyond economic indicators, such as yields per hectare, or environmental impacts, such as measures of biodiversity loss. The Framework can also allow for comparisons between substitutes – for example, between palm oil and other edible oils – to see how they compare not only in terms of economic outcomes, but also environmental, social and health outcomes. Section 4 describes the application of the Framework in more detail.

One way of characterizing the difference between a traditional, production-only approach and the systems approach of the Framework is to consider that the production-only approach is generally limited to those stocks, flows and outcomes that are observable or visible in markets and hence are reflected in standard economic statistics. While this is sufficient to support detailed economy-wide and sector level economic modelling, a systems approach more fully captures a significant range of invisible or non-market stocks and flows that must also be considered. These flows may be unpriced and not incorporated into standard macro and sector level economic modelling, but they are undoubtedly real stocks and flows that can be observed and described. The TEEBAgriFood Evaluation Framework is the articulation of a response to this integration challenge.

The underlying conceptual approach used in the Framework is a multiple capitals or accounting approach, commonly described as a wealth accounting approach (see, for example, Arrow *et al.* 2013; Lange *et al.*2018; UNU-IHDP and UNEP 2014; IISD 2016). Inherent in accounting-based approaches is a requirement to articulate the differences and connections between stocks and flows. This is a fundamental requirement in understanding the dependencies inherent within systems in terms of the current condition and composition of stocks and the associated capacity of the four capitals (produced, natural, human and social) to provide flows of benefits into the future.

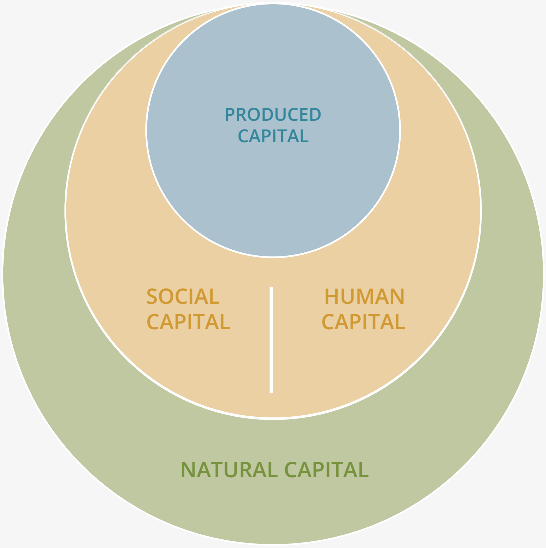
6.3.2 Key elements of the Framework

Stocks

Understanding the quantity and quality of the stocks that underpin eco-agri-food systems is essential in understanding the full range of impacts and dependencies these systems create. Fundamental to the Framework, and consistent with the discussion on systems in Chapter 2, is the notion that there are real connections among: (i) the stocks that provide the base for assessment of capital (ii) the production and consumption of goods and services, (iii) the consequential outcomes and (iv) the associated impacts on human well-being from eco-agri-food systems. Historically, the focus has been on the production of agricultural goods with limited connection to understanding the changes in the full range of stocks or the broader outcomes and impacts of productive activity. The development and design of this Framework aims to provide a platform for recognizing the breadth of dependencies and impacts within eco-agri-food systems. To this end, the various stocks are clearly distinguished from the flows of inputs and associated outcomes that they generate. Analysing these distinct elements supports a better understanding of issues such as capacity, sustainability, productivity and efficiency.

In the TEEBAgriFood Framework, the stocks are classified to align with four types of capital following the Inclusive Wealth Report (UNU-IHDP and UNEP 2014) and Forum for the Future (2015). The types of capital are produced, natural, human and social capital, recognizing there is an ongoing discussion on the choice of terms and measurement boundaries. The key point is that *all* capitals are in scope of the Framework. **Figure 6.5** shows the links between these four types of capital, and the following section provides definitions of each of these capitals.

Figure 6.5 Four types of capital (adapted from Forum for the Future 2015)



Definitions of capital

The following definitions of capital provide a basis for discussion of appropriate measurement boundaries in the context of this Framework.

Produced capital[4] incorporates all manufactured capital such as buildings, machines and equipment, physical infrastructure (roads, water systems), the knowledge and intellectual capital embedded in, for example, software, patents, brands, etc., and financial capital.

Since produced capital such as machinery, storage facilities and transport equipment is often under the ownership of individual economic units, it should be recorded for all businesses within the agri-food value chain, including small scale and subsistence producers. In addition, at least conceptually, an allocation should be made concerning capital inputs from built infrastructure essential to the function of the agri-food value chain, for example, from road and rail networks, ports and airports, and dams and irrigation systems, even if such infrastructure was not constructed exclusively for use by agri-food production systems. In many cases this infrastructure will be under public sector ownership and management. Knowledge capital arising from agricultural research and development should be considered a part of produced capital, as it either determines or adds value to the underlying stock in which it is embedded – drought resilient seeds or smarter irrigation infrastructure, for example. Where knowledge capital is embedded in people or communities it should be included as part of human or social capital, for example indigenous ecological knowledge.

The measurement of the stocks and flows associated with produced capital should be aligned with the concepts and definitions of accounting standards (at either corporate or national level, e.g. using definitions from the System of National Accounts).

Natural capital refers to “the limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services” (TEEB 2010b) For measurement purposes, following the SEEA, it incorporates the “naturally occurring living and non-living components of the Earth, that in combination constitute the biophysical environment” (UN 2012). It thus includes all mineral and energy resources, timber, fish and other biological resources, land and soil resources and all ecosystem types (forests, wetlands, agricultural areas, coastal and marine, etc.).

Biodiversity at all levels (ecosystem, species, genetic), and in terms of both quantity and variability, is considered a key characteristic of natural capital. Biodiversity underpins ecosystem functioning. Ecosystem services are considered flows generated by natural capital that contribute to production and consumption and, more broadly to human well-being (Díaz *et al.* 2015).

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[4] The term “produced capital” is used for consistency with the concept measured in the UNU-IHDP Inclusive Wealth Report (UNU-IHDP and UNEP 2014). Other terms such as physical capital, manufactured capital and reproducible capital are also used, sometimes with a different scope from the definition used here. Note that the concept of “produced capital” used here is broader than the concept of “produced assets” as applied in the System of National Accounts.

The connection between natural capital and eco-agri-food systems can be seen from two perspectives: the role that natural capital plays in supporting agricultural production, and the effects that agricultural production has on the condition of natural capital. In terms of supporting agricultural production, the initial focus should be on measuring the natural capital associated with agricultural production namely land, soil and water resources and the associated ecosystems and biodiversity that provide the required ecosystem services. These elements of natural capital may be located on-farm and hence under the management of agricultural units, or they may be off-farm and hence influenced by the management decisions of other units. (Consider, for example, dependence on upland forests for flood control and aquifer replenishment, or on areas of native vegetation providing habitat for pollinators).

For other activities across the value chain, such as food processing and distribution, assessment may be made of the land used by or owned by the companies involved in these activities. Generally, the area of land used by these activities is likely to be small relative to the area of agricultural land, therefore requiring a much lower dependence on ecosystem services as direct inputs.

In terms of recording the effects of eco-agri-food systems on natural capital, a wide range of types of natural capital may be involved depending on the types and locations of production systems. Common areas of focus will be assessing the effect of eco-agri-food systems on water resources, in terms of both quantity and quality, measuring emissions to the atmosphere, and accounting of loss of native vegetation and associated biodiversity.

Human capital refers to “the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being” (Healy and Côté 2001)[5]. It is most commonly considered in the context of inputs to the production of goods and services and hence limited to the skills and experience of the labour force. However, conceptually it can be extended to incorporate, for example, the production of household services such as raising children and managing a household. Human capital will increase through growth in the number of people, improvements in their health, and improvements in skills, experience and education of a population. This includes traditional and indigenous knowledge, which may be of particular importance in agricultural production systems. Human capital depreciates as skills and experience are lost and will be affected by changes in human health conditions.

With respect to eco-agri-food systems, the initial focus in the measurement of human capital should be on the labour force, including the self-employed. It is useful to understand measures of human capital in terms of its composition (e.g. age, gender, migrant status) and in terms of the quality or condition of the capital base including levels of educational attainment, measures of traditional and indigenous knowledge and health status.

A range of other labour related indicators also need to be captured in a complete evaluation, such as information on employment, ‘decent’ working conditions[6], and occupational health and safety (ILO 2013). In the Framework, employment aspects are captured as direct inputs to eco-agri-food production (see below) while those aspects that relate primarily to the conditions of employment are considered in the context of social outcomes, where they can be directly connected to individual parts of the eco-agri-food value chain.

Social capital encompasses “networks together with shared norms, values and understandings that facilitate cooperation within or among groups” (Healy and Côté 2001). Social capital may be reflected in both formal and informal arrangements and can be considered the “glue” that binds individuals in communities. More broadly, it can be seen as the form of capital that “enables” the production and allocation of other forms of capital (UNU-IHDP and UNEP 2014).

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[5] Note that knowledge embedded in produced capital, e.g. software, patents, etc, is included under produced capital.

[6] In 2008, the ILO adopted a framework of Decent Work Indicators that was presented to the 18th International Conference of Labour Statisticians in December 2008. The Framework on the Measurement of Decent Work covers ten substantive elements which are closely linked to the four strategic pillars of the Decent Work Agenda, that is: (i) International labour standards and fundamental principles and rights at work (ii) Employment creation (iii) Social protection and (iv) Social dialogue and tripartism (ILO 2013)

While social capital has proved difficult to measure (Giordano *et al.* 2011) and aggregate indicators are not widely agreed upon, various proxies (e.g. indicators of the strength of social networks, measures of trust (Hamilton *et al.* 2017) may give insights into the extent and condition of social capital. Some of these indicators include collective action and cooperation, adherence to norms and regulations, participation in local organizations and groups, and social cohesion and inclusion (Grootaert *et al.* 2002). For example, capturing information on the number of farmer's cooperatives and their functioning across agricultural production systems may provide valuable insights for decision-making. Similarly, understanding the participation and inclusion of women and other marginalized sections across agricultural systems is vital to informed policy-making.

Given the breadth and fluid nature of social capital, determining an appropriate boundary for its measurement in the context of this Framework is difficult. Nonetheless, in line with the other capitals, the initial focus is on the role that social capital plays in production through the eco-agri-food chain, i.e. measures that indicate the extent and condition of social networks, inclusion of marginalised sections of society, and relationships and institutional arrangements that support production. One important perspective on social capital is social equity, which is discussed in greater detail in Chapter 5.

In the context of the Evaluation Framework, the range of issues covered with respect to social capital is focussed on the issues that can be linked directly with specific agricultural production systems and processes along the eco-agri-food value chain. This focus is narrower than would be included in a complete assessment of social capital for a community or country which will also incorporate non eco-agri-food system perspectives, but the themes that emerge in considering this narrower focus are nonetheless very relevant and cover a broad spectrum of concerns.

Recording information on the stocks of capital

In assessing an eco-agri-food system, initial focus should be on recording the stocks of capital, i.e. the available quantity (*extent*) and quality (*condition*) at a point in time, and changes in the stock over time. Changes may result from investment, use or extraction, catastrophic loss or ongoing depreciation and degradation. In order to understand the prospects for sustainable generation of services and benefits from the stocks, it is important to capture information on the physical characteristics of the stocks.

Recording information on physical characteristics may appear most appropriate in the context of natural capital but similar indicators can also be developed for produced and human capital. For example, taking note of the number and average age of farm machinery and the size and education level of the farming workforce will provide valuable information on the produced and human capital base of eco-agri-food systems. For all capitals, information on the distribution of ownership and use, for example, by industry or population sub-group, can also help in understanding the stock of capital.

Knowing the monetary value of different stocks is also important in understanding economic behaviour associated with the use of stocks. For example, monetary values may help explain the extent of return on investment and inform on the level of financial resources required to maintain ownership and management of stocks.

A common concern in the use of monetary values of capitals in decision making is the implication that all capitals are substitutable in the broader ambition to maintain and increase total wealth. That is, in purely monetary terms, substituting between natural and produced capital may appear to be an appropriate strategy. In reality, stocks of natural capital in particular are subject to important non-linearities and threshold effects such that while some degree of substitution may have little effect on the condition of natural capital, ongoing substitution will likely have significant negative consequences. Further, recent research highlights that standard cost-benefit analyses and economic methodologies assume that natural capital can be easily substituted, when in fact it cannot and economic models are ill-equipped to illuminate dependencies between capitals (Cohen *et al.* 2017). Important concerns in the use of these models include:

1. the absence of markets for natural capital thus limiting the potential for appropriate integration with produced capital;
2. the focus on substitution at the margin which will tend to ignore thresholds in the use of natural capital (i.e., ignoring critical natural capital) and the effects of scale (i.e., that substitutability at large scales need not imply substitutability at local scales)
3. the extent to which the potential for substitution changes over time.

The appropriate response to these concerns from an evaluation perspective is to ensure a comprehensive assessment of all information (biophysical, qualitative and monetary) on all capitals. Such an assessment will make clear the extent of substitutability between capitals in any given eco-agri-food system and the associated issues of thresholds in the use of capital.

The measurement boundaries for different capitals may be difficult to apply in practice. For example, depending on the context, knowledge capital may be measured under produced, human or social capital. Therefore, it is sufficient to ensure that all stocks are incorporated under some type of capital; their omission is of far greater concern than their classification.

At national level, it is recommended that measures of produced capital be compiled in line with the definitions and concepts of the System of National Accounts and that measures of natural capital be compiled in line with the definitions and concepts of the System of Environmental-Economic Accounting. Together, these two UN statistical standards provide a comprehensive and integrated measurement of produced and natural capital. Guidelines for the measurement of human capital have also been developed (see, for example, UNECE 2016), and can be applied for eco-agri-food systems. As noted above, the measurement of social capital is the least developed but progress is being made towards improved guidance for measurement in this area (see for example, OECD 2018 and Siegler 2014). Chapter 5 describes a model for characterizing the relevant elements of social capital in the context of eco-agri-food systems.

In addition to information on the physical characteristics and monetary value of different types of capital, it is increasingly common for the stocks of capital to be considered in relation to concepts such as resilience, diversity, capacity and sustainability. For the TEEBAgriFood Evaluation Framework, these concepts are seen as characteristics of the underlying stocks. That is, there must always be an underlying stock that is resilient, diverse, has capacity or is sustainable.

In measurement terms, some of these concepts are not directly observable but must be assessed by integrating measures of multiple elements. For example, species level biodiversity can be assessed through surveying numbers of different species; but the associated levels of ecosystem sustainability and capacity must be assessed by considering the condition of the associated ecosystem (in providing suitable habitat) and the expected patterns of use of the ecosystem. Since the Framework incorporates measures of these various elements, indicators of resilience, diversity, capacity and sustainability will be able to be derived from the Framework.

Flows through the value chain

The theory of wealth accounting that underpins the description of capitals within the TEEBAgriFood Evaluation Framework also contains a conception of flows that reflects the benefits derived from the use of the various stocks. This embedded discussion of stocks and flows, present in all accounting-based frameworks, underpins a range of analytical choices including the assessment of contributions to well-being.

While the theoretical basis for linking stocks and flows within accounting systems is well established, in practice, the variety of types of flows can make articulation and measurement a challenging exercise. Flows include capital inputs (including inputs from produced capital, labour from human capital, ecosystem services from natural capital and inputs from social capital); flows of goods and services through the agri-food system (including agricultural and food products and manufactured input such as fertilizers, pesticides, fuel and electricity); and residual flows arising from production and consumption activity such as GHG emissions, excess nitrogen, harvest losses and food waste. Mapping these various flows into, within and from the agri-food system allows a full articulation of the pathways by which an eco-agri-food system impacts human well-being.

However, information on each of these types of flows is not equally available. Some flows are visible or final, in the sense of being observed in markets and standard reporting arrangements, while others are intermediate, and often invisible, in the sense of usually being ignored in decision-making. For example, while pollination services are intermediate flows that contribute to yields, since it is yields that are captured in the market, the role of pollination services is often ignored. Therefore, while several of these intermediate flows will be implicitly embedded within final flows, it is important to recognize and record the intermediate flows separately. A primary aim of the Framework is to ensure all flows, and associated stocks, are made visible in decision-making.

With that in mind, and keeping in line with the general structure of statistical and reporting standards, the four key types of flows reflected along the value chain are:

- **agricultural and food outputs**
- **purchased inputs**
- **ecosystem services**
- **residuals**, including food loss and waste along the value chain

It should be clear from **Figure 6.3** that the coverage of the Framework is not limited to recording flows in relation to agricultural production systems. Instead the Framework extends to the full eco-agri-food value chain, encompassing activities of manufacturing and processing, distribution, marketing and retail, and household consumption. The TEEBAgriFood value chain is described later **Table 6.2**; it is sufficient to recognize at this point that the four key types of flows should be recorded in relation to all stages of the value chain. The relative importance of different flows will vary at different stages of the value chain and will depend on the type of eco-agri-food system under consideration. The Framework also supports a focus on particular flows across the value chain. For example, the Framework supports description and analysis of harvest losses and food waste from production through to consumption.

Purchases and sales of investment goods such as machinery, equipment and buildings (i.e. types of produced capital) may be considered another type of flow. These are not treated as flows in the TEEBAgriFood Evaluation Framework but are instead included as changes in the stock of produced capital and hence recorded as produced capital outcomes.

Agriculture and food outputs

Understanding the flows of agricultural and food outputs along the value chain is fundamental to setting the scope of analysis and to making clear material dependencies and impacts. Understanding these flows also clarifies the relevant spatial scales for analysis since some eco-agri-food systems may be contained at the farm and community scale while others will involve connections around the globe.

Given the length and breadth of multiple branches of the value chain in this Framework, an initial focus on products reflects their primacy of importance. In effect, the logic of the Framework involves tracking the supply and use of 'agricultural and food products' through the value chain. At a macro level, the recording here relates directly to the concept of food balance sheets[7] as developed by FAO (2001). At a micro level, it relates to concepts of traceability.

Since it is not usually meaningful to aggregate quantities across all agricultural commodities, this information should be recorded by type of commodity (e.g. wheat, rice, beef) and classified by type of farm, type of production practice, or other aggregation. Generally, this information would be recorded in tonnes or similar production equivalent. From this base however, conversion using appropriate factors is possible; for example, products might be assessed in terms of the quantity of protein produced, or in terms of micro-nutrients. This nutritional information can help link the value chain to outcomes for human health.

Complementing these flows of output recorded in physical terms are measures of income. Income measures include economic value added in monetary terms, and the return to businesses as operating surplus (profit), as measured at national level in a countries' national accounts and input-output tables (IMF 2007). A complete set of accounts provides a comprehensive set of information as well as visibility for these flows, and will also cover flows of 'subsidies, taxes and interest'. It is not necessary for the Evaluation Framework to list all of these flows in a strict accounting format as such advice is already present in international statistical standards (e.g. the System of National Accounts). It is sufficient to recognize the flows that are likely to be of primary focus in the analysis of the eco-agri-food value chain, such as those just listed.

Data on flows such as income, costs and value-added is relevant for all businesses within scope at all stages of the eco-agri-food value chain. Data will most commonly be recorded in monetary terms and hence can be aggregated across industries within a study. Making comparisons over time will often necessitate adjustment for changes in relative prices (converting data to constant prices / measuring price adjusted volumes). When making comparison among countries, it will be necessary to allow for the differences in purchasing power of different currencies (using purchasing power parities). Furthermore, and especially in the context of agriculture, it is important to include trade barriers, subsidies for inputs, and other market distortions in any evaluation.

Measurement of these variables over time will provide insights into the resilience of producers since income flows in agriculture may be particularly volatile from year to year, depending on prices for agricultural outputs or inputs, and the impacts of climatic events.

Purchased inputs

A complete understanding of the production process across the value chain requires an understanding of the quantities and values of different inputs. The purpose in recording these flows is to recognize where there might be particular pressure points in supply. The focus here is on purchased inputs, comprising 'labour inputs' and also 'intermediate consumption'. Labour inputs refer to paid or salaried work along the agriculture and food value chain and can be measured in monetary terms and also in terms of its characteristics such as skills, experience, etc. Intermediate consumption, following the SNA, refers to the goods and services produced by economic units that are consumed within production processes. Examples include water, energy, fertilizers, pesticides, animal health and veterinary inputs.

Different production approaches for the same commodity (e.g. between intensive and extensive production systems) create differences in the use of purchased inputs. Trade-offs also vary when it comes to the use of purchased inputs and reliance on natural ecosystem services that provide the same type of input, for instance, irrigation versus direct rainfall, fertilizer use versus soil management and pesticide use versus biological pest control. Consistent with the SNA and the SEEA, the measurement boundary for purchased inputs includes all water and energy use whether purchased from suppliers or abstracted/produced on "own-account".

Data on purchased inputs is available mostly from farm level surveys and censuses and can be collated in aggregate form in national accounts datasets and related

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[7] Food balance sheets provide essential information on a country's food system through three components:
- Domestic food supply of the food commodities in terms of production, imports, and stock changes.
- Domestic food utilization which includes feed, seed, processing, waste, export, and other uses.
- Per capita values for the supply of all food commodities (in kilograms per person per year) and the calories, protein, and fat content

input-output tables in monetary terms. Information on flows of inputs in physical terms is also important for analysis. Key inputs in this regard are water use, energy use (including information on the type energy source, such as renewable energy), pesticide and fertilizer use (N, P, K). For agricultural producers, the SEEA AFF provides guidance and accounting tables to organize relevant information.

Ecosystem services

As is increasingly recognized (Swinton *et al.* 2007), a focus on the marketed outputs and inputs of agri-food systems ignores the significant role of ecosystem services in the production of crops, livestock and other outputs. These services include biomass accumulation, pollination, and water and soil related services. Ecosystems also provide a range of additional services helpful in agricultural landscapes and elsewhere, such as carbon sequestration, water regulation, biodiversity and amenity values. While several classifications of ecosystem services exist (MA 2005; EEA 2018; US EPA 2018), the TEEBAgriFood Evaluation Framework distinguishes between 'provisioning', 'regulating' and 'cultural' services, by way of example[8]. An important role of the Framework is to help assess trade-offs. These include trade-offs between ecosystem services as inputs to production and corresponding purchased inputs (e.g. with respect to fertilizers) and the potential trade-offs between different land use types, such as use of ecosystems to support agriculture versus the supply of other ecosystem services that are of broader public benefit, such as carbon storage and the provision of habitat to support maintenance of biodiversity.

The range of ecosystem services that is relevant as inputs to agriculture varies depending on the production system and output being produced but typical examples include water services (e.g. water absorbed from soil), soil services (including nutrient cycling), grass for grazing livestock, and pollination services (from wild pollinators). Ecosystem services may be supplied by ecosystems located on the farm or by neighbouring ecosystems (e.g. where pollinators live in nearby bush or forest). Recording the source of ecosystem services, including by ecosystem type, helps provide a clear sense of the types of ecosystems that should be maintained to support agricultural production. The ecosystem services considered in a given assessment should be made explicit and use a commonly accepted classification such as CICES as a type of checklist (EEA 2018).

The more details about production processes and agricultural outputs that can be captured, the more useful the Framework will be. The comparison of the mix of purchased inputs and ecosystem services inputs is of particular interest. For example, assessing the differences in outcomes between production approaches using high levels of fertilizers and approaches using more organic means of soil management (and hence increased use of ecosystem services). In this regard, it is important not to limit analysis of ecosystem services and other inputs to the flows themselves, but to extend analysis to consider changes in the underlying capital base (e.g. soil condition, pollinator diversity, off-farm water quality). This will allow an informed assessment of the capacity of farms and farming landscapes to continue to operate in their current fashion.

In addition to the use of ecosystem services as inputs to agricultural production, farming areas supply a range of ecosystem services that benefit other economic units, households and society generally. Examples of these types of services include climate regulation (e.g. via carbon sequestration), soil retention and the amenity values from farming landscapes.

Since these ecosystem services are generally not for sale, their generation by farming areas will not be included in the valuation of production nor will the loss of these services be captured in economic values if the underlying natural capital is degraded. Exceptions will arise in cases where farmers can participate in payment for ecosystem services (PES) schemes, for example where an income is generated from demonstrating increases in the capture of carbon. Overall, recording all flows of ecosystem services generated from farming landscapes is an important part of providing a more complete picture of the eco-agri-food system.

The focus for measurement of ecosystem services inputs in this Framework is on agricultural production only and is not extended to the production of other outputs along the eco-agri-food value chain, e.g. food processing and distribution. It is noted however that where the flow of agricultural products can be traced through the value chain, useful estimates can be made of the effective embodiment of ecosystem services and various stages of production through to final consumption.

Many agricultural production areas comprise a mix of ecosystem types. With regard to individual agricultural holdings there is often a dominant ecosystem type – e.g. cropland or grassland – but there is also often a mix of native vegetation and other features that create

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[8] For the purposes of CICES, ecosystem services are defined as the contributions that ecosystems make to human well-being. Provisioning services include all material and energetic outputs from ecosystems; they are tangible things that can be exchanged or traded, as well as consumed or used directly by people in manufacture. Regulating services include all the ways in which ecosystems control or modify biotic or abiotic parameters that define the environment of people, i.e. all aspects of the 'ambient' environment; these are ecosystem outputs that are not consumed but affect the performance of individuals, communities and populations and their activities. Cultural services include all non-material ecosystem outputs that have symbolic, cultural or intellectual significance (EEA, 2018)

agricultural “mosaics”. And, increasingly, farmers are being encouraged to ensure that a portion of their land is allocated to nature conservation, for example by fencing off riparian zones. By recognizing that farmers manage a range of ecosystem types and by recording the associated streams of ecosystem services under their purview that are of public benefit, a more complete estimate of production by farms can be recorded.

Further, the scope of measurement should include ecosystem types that surround agricultural holdings, such as forests and rivers. Each of these, in different ways, provides ecosystem services as inputs, and can be impacted by agricultural activity. It is therefore relevant to monitor flows of ecosystem services from these ecosystems as part of the systems approach of TEEBAgriFood.

The measurement of ecosystem services is a rapidly developing area, with many initiatives underway at local, national and global levels. As yet, however, there is no single authoritative database akin to the availability of data on agricultural production and purchased inputs. Nonetheless, there are reasons to be optimistic about the availability of this information in the foreseeable future.
First, part of the development of the SEEA has involved the integration of measures of ecosystem services and their values within an extension of the SNA. This provides a common platform for bringing together economic and ecosystem data. Through the SEEA Experimental Ecosystem Accounting, there is now a statistical basis to account for ecosystem services, though ongoing research and further development of methods and classifications is still needed.

Second, a range of implementation activities focused on advancing the SEEA based ecosystem accounting framework are taking place around the world. At national level, leading countries in ecosystem accounting include Australia, Canada, Mexico, the Netherlands, the Philippines, South Africa and the US. At international level, there are programs being led by the World Bank (WAVES), the EU for Europe, and UNEP and UN Statistics Division for Brazil, China, India, Mexico and South Africa. Experience in these projects is demonstrating that the logic of ecosystem accounting is directly applicable at farm and local levels, and projects to test ecosystem accounting at these scales are being developed.

All of this work has established a global community on ecosystem accounting that can directly support measurement in this aspect of the TEEBAgriFood Evaluation Framework and, more broadly, in the measurement and valuation of natural capital itself. Further, testing of the TEEBAgriFood Evaluation Framework can contribute to the ongoing advancement of ecosystem accounting and broader recognition of the need for more comprehensive measurement of non-market stocks and flows.

Residuals

Recording residual flows along the value chain is an important part of assessing the overall impact of production and consumption processes. Following the SEEA Central Framework, residuals are “flows of solid, liquid and gaseous materials, and energy, that are discarded, discharged or emitted by establishments and households through processes of production, consumption or accumulation” (UN 2012). The TEEBAgriFood Evaluation Framework aims to record all such residual flows that occur as a result of the activities that take place within the eco-agri-food system.

Recording these residual flows in the Framework does not include a judgement as to whether they have a positive or negative impact on human well-being. Indeed, some residuals may be recovered and recycled within or between establishments and households. Understanding both the gross and the net flows of residuals is important in understanding the overall dynamics of the eco-agri-food system.

Recording residual flows reflects a measure of pressure rather than changes in natural or human capital or impacts to environment or health. Thus, it is important to also consider the resulting changes in the capital base of the “receiving” ecosystems or populations. These are recorded as outcomes in the next part of the Framework. Potentially significant thresholds and non-linearities need to be considered, especially with respect to time since it may take many years for the full effects of the release of residuals to become apparent.

It is also important to distinguish between residual flows and outcomes and to pinpoint their sources (as possible) along the eco-agri-food value chain. This may be more tractable at a local community or landscape scale where the activities of all relevant farms or manufacturers can be considered in aggregate, rather than seeking attribution to individual farms and businesses. Attribution of residual flows at too high a level of aggregation, for example by sector, may miss the reality that the outcomes are often highly specific to location.

Five categories of residual flows are described in the TEEBAgriFood Evaluation Framework as shown earlier in **Figure 6.3**. Detailed definitions and accounting treatments for these flows are described in the SEEA Central Framework and, for agricultural production, in the SEEA AFF. Short descriptions of the categories are provided below.

Agricultural and food waste

A significant proportion of food is wasted or lost along the eco-agri-food value chain, including harvest losses at the farm level, losses during storage, distribution, and processing of food, and food waste resulting from human consumption (FAO 2013). The explicit inclusion of waste in the Framework is essential. Different parts of the value chain generate waste differently and in varying amounts. Using efficiency measures (tonnes of food waste per tonne of output or consumption) and tracking "weak" points in the value chain – for example, the effectiveness of cold storage facilities for perishable products - can provide significant information helpful to the goal of reducing waste. Food waste is normally measured in tonnes but conversion to monetary value, calories or nutrients can support other areas of analysis and make inefficiencies clearer.

A distinction should also be made between the tracking of food waste through the value chain as described here and the collection and treatment of waste by the waste industry. Despite this distinction, it is relevant where possible, to record recovery and recycling of food waste, for example through composting or the work of food charities to recover surplus food to feed needy people. Furthermore, losses that arise during manufacturing, processing and subsequent transformation should be treated as food waste, except where losses are re-purposed, e.g. for animal feed, in which case there may be only a partial loss of economic value. Capturing this information will help make clearer the net impact of food waste on human well-being.

Greenhouse gas (GHG) emissions

GHG emissions measurements[9] for agriculture should include those produced by process emissions (including enteric fermentation, manure management, rice cultivation, synthetic fertilizers, manure left on pasture, crop residues, manure applied to soils, drained organic soils and burning of crop residues), emissions from energy use, and AFOLU based emissions relating to the management of forests, cropland and grazing land, the clearing of forest land and the draining of organic soils. GHG emissions for other parts of the eco-agri-food system should also accord with the UNFCCC reporting requirements (IPCC 2018).

Other emissions to air, soil and water

Other emissions of agri-food systems may include excess nitrogen (N) and phosphorous (P) from inorganic sources that is released from agricultural land, pesticide and chemical runoff, particulate matter (PM10, PM2.5), heavy metal pollutants, and sulphur dioxide. While measurement challenges exist, there are well-established frameworks for measuring and modelling the transport and fate of several of these at farm, regional and national scale. These can be used as the basis for gathering data in a TEEBAgriFood context.

Wastewater

Wastewater is discarded water that is no longer required by the user and is discharged directly to the environment, supplied to a sewerage facility or supplied to another economic unit for further use. Guidance on the measurement of wastewater is provided in the SEEA Water and the International Recommendations on Water Statistics.

Solid waste and other residuals

This category is designed to encompass all other residual flows not included in the categories above. Examples include solid waste such as packaging waste and discarded equipment.

Outcomes

Outcomes are the third key element of the TEEBAgriFood Evaluation Framework. Within an accounting-based framework, outcomes are fully reflected as changes in the extent or condition of the stocks of capital due to value-chain activities and hence can be described in terms of the changes in the four types of capital – produced, natural, human and social. These changes may be positive, i.e. increases in the stock of capital, or negative. Recording outcomes as changes in the stock of capital embeds the application of the systems approach that is foundational to the TEEBAgriFood approach.

It is not the role of the Framework to articulate all of the possible positive and negative outcomes. Rather, the intent is to provide a means by which all outcomes can be placed in a common context. Thus, through regular and ongoing measurement, it is possible to establish a dynamic picture of change in eco-agri-food systems that allows deeper understanding of the many and varied relationships within the system.

There is a direct relationship between the groupings of capital described above and the groupings of outcomes, noting the many potential connections between each type of capital and the different types of flows. By way of example, in cases where there is a recorded flow of pollution arising from food processing activities making its way into a local waterway, there are possible negative outcomes for both natural capital (a decline in 'water quality') and human capital (declines in 'human health'). Also, for example, activity to restore riparian zones in grazing lands can lead to positive outcomes

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[9] Following the System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries (FAO and UN 2018) and IPCC (2018).

in terms of improved natural capital conditions and in terms of improved productivity that increase returns to produced capital. Similarly, improvements in public food distribution systems can lead to positive outcomes for social capital (through greater 'food security') and human capital ('improved nutrition').

The examples of outcomes provided throughout this chapter are indicative only, and as noted above, the composition, extent and direction of shifts in the stock of capital may vary significantly across different eco-agri-food systems.

It is also important to assess as to how these outcomes may be distributed across stakeholders. For example, establishment of minority self-help groups would empower minority communities in rural areas, improving both their stocks of social and human capital. Similarly, while certain agricultural technologies may increase financial wealth (increasing produced capital base) of farmers, it would be important to assess how this may be distributed across small scale and large scale farmers. Depending on the extent to which information is available to populate the Framework, it would be possible to assess changes in the stock of capitals for small landholders, local communities, food processors, governments, etc. and for different household groups, for example in terms of gender, income, age and location (urban/rural).

As noted in the discussion on stocks, an important consideration in understanding eco-agri-food systems is the extent of their vulnerability and resilience to systemic change and shocks. In the TEEBAgriFood Evaluation Framework, concepts such as vulnerability and resilience are embedded in the concept of capital and the underlying stock. Thus, the resilience of a specific eco-agri-food system will be reflected in the condition of its stocks and their balance or composition. In turn, changes in resilience will be reflected in the measurement of outcomes. Thus, measures of outcomes will embody the non-linear and dynamic descriptions of the state of eco-agri-food systems.

For example, the resilience of a small scale maize producer to climate change will, among other factors, be reflected in the condition of the soil and access to water. To the extent that changes in natural capital can be measured, then the measured outcomes will show the changing resilience of that specific production system and also reflect the non-linear and dynamic effects that take place. Overall, recording outcomes in the Evaluation Framework is a fundamental to describing all eco-agri-food systems in a comprehensive way using a common platform. The set of information obtained from recording stocks, flows and outcomes will support a wide range of economic and other analysis, as well as the development of indicators and metrics to monitor progress towards goals such as sustainability.

Impacts – contributions to human well-being

Recording stocks, flows and outcomes provides a complete description of eco-agri-food systems but does not provide a standardized interpretation of the relative differences among various systems with respect to human well-being. Moreover, since we aim to compare farm systems across their economic, social, and environmental dimensions, it is important to integrate these dimensions in a meaningful way that can inform policy and business decision-making. Using a single, common approach allows for consistent and coherent comparisons.

Several analytical tools are available to assess eco-agri-food systems and their impacts on human well-being. These include, for example, cost-benefit analyses, integrated profit and loss statements, ecosystem services valuation, and measures of inclusive wealth. In practice, these tools are often partial in coverage and there is a need to account for social and environmental considerations that are often left out. For example, while cost benefit analyses may include direct social and environmental impacts, they often do not include comprehensive assessments of ecosystem services, nor broader social equity considerations. Such factors are not naturally incorporated into economic valuation approaches premised on the existing distribution of wealth and capital.

For the TEEBAgriFood Evaluation Framework, we propose a value addition-based approach to more holistically assess the impacts of eco-agri-food systems in terms of their balance of contribution to human well-being. Following the TEEBAgriFood interim report, 'value addition' reflects the idea that it is possible to change the state (space, time, and characteristics) of a product to make it more valuable to humanity. Standard metrics for measuring value addition focus on visible or market price-based measures. Thus, at the business level, value addition is a measure of operating profit, i.e. sum of factor returns and surplus generated by firms over and above their purchases from other firms. At the national level, the System of National Accounts (SNA) incorporates value addition through the income approach of calculating the Gross Domestic Product (GDP) indicator, which is the sum of compensation of employees, taxes less subsidies on production, and the operating surplus of the producer.

However, such metrics generally ignore the economically invisible flows that form important components of eco-agri-food systems. To address this gap, the coverage of value addition is broadened to incorporate the contribution of invisible and visible flows to human well-being through their positive (or negative) impacts along the agricultural value chain.

For example, while malnutrition is a human capital outcome, it can also have significant material impacts on productivity. Similarly, while biodiversity loss is a natural capital outcome, this can lead to reduced supply of ecosystem services and thus negatively impact agricultural yields and returns to produced capital. **Table 6.1** provides a series of examples of the links between different outcomes and impacts. Note that these examples are hypothetical, and the actual impacts for a particular eco-agri-food system will depend on the specific context.

Using the techniques and methods described in Chapter 7, and based on the descriptive information on stocks, flows and outcomes, the broad ambition of the TEEBAgriFood Evaluation Framework is to assign values, either positive or negative, to the significant (material) impacts of eco-agri-food systems and hence evaluate the relative impact of different eco-agri-food systems on human wellbeing. There is no doubt this is a challenging goal. Indeed, while a range of economic, health and environmental impacts can be valued using established methodologies, other impacts, in particular social impacts, do not easily lend themselves to monetary analysis. For example, the impacts of social capital outcomes such as food security may be very difficult to capture quantitatively, let alone in terms of 'value addition'. The complete evaluation of impacts therefore should accommodate qualitative assessments of some variables. This will involve presenting information on impacts relating to, for example, food security, access to nutritious food, gender equity in land holdings etc., utilizing the information reflected in other parts of the Evaluation Framework.

Table 6.1 Examples of outcomes and impacts, as expressed by value addition (Source: authors)

Outcome Type	Potential Outcome Details	Potential Impact (expressed by value addition)
Natural capital outcome	Higher GHG concentrations	Productivity losses through increased drought/ flooding
Natural capital outcome	Deforestation	Loss in relevant ecosystem services inputs, leading to productivity losses
Natural capital outcome	Higher water yields	Improved crop yields due to increased water availability
Natural capital outcome	Improved condition of tree belts and hedgerows	Increased amenity values
Natural capital outcome	Eutrophication of water ways	Reduced income from fish catch
Social capital outcome	Land displacement	Reduced income and qualitative indicators concerning equity, including gender equity
Social capital outcome	Increased access to food	Assessed health benefits and qualitative indicators concerning equity
Social capital outcome	Increased opportunities of employment for women in rural areas	Qualitative indicators on equity and community networks
Human capital outcome	Improved nutrition	Decrease in health costs/ increased productivity
Human capital outcome	Reduced occupational health due to pesticide poisoning	Increased health costs due to higher disease burden
Human capital outcome	Improved skills	Higher income due to increased skills set
Produced capital outcome	Investment in agricultural machinery	Improved farm incomes and productivity
Produced capital outcome	Loss of road infrastructure	Increased transportation costs and higher consumer prices

Stages of the eco-agri-food value chain

Beyond extending the assessment of eco-agri-food systems to encompass all types of stocks, flows and outcomes and to evaluate economic, health, social and environmental impacts, the TEEBAgriFood Evaluation Framework also seeks to extend assessment across the complete eco-agri-food value chain. Smaller sections of this chain are already being analysed. From an economic and corporate perspective, the analysis of value and supply chains is relatively common (Dania *et al.* 2016), for example using general equilibrium modelling in the analysis of international trade. In the area of food security, analysis commonly considers the connection between the supply of food products and the consumption of food products (e.g. FAO food balance sheets [FAO 2001]). In health fields, there is ongoing research into the link between dietary patterns and health outcomes.

However, the TEEBAgriFood Evaluation Framework is unique in connecting all of these parts in order to study the full effects of the eco-agri-food value chain, i.e. the production chain, the link to consumption and the final link to outcomes for human health. Within the Framework, the stages of the eco-agri-food value chain have been broken into four main groups – agricultural production; manufacturing and processing of food products; distribution, marketing and retail; and household consumption. These four groups are intended to provide a complete coverage of the value chain. **Table 6.2** presents the four groups of the TEEBAgriFood value chain and relevant sub-groups.

Table 6.2 The TEEBAgriFood value chain (Source: authors)

TEEB AgriFood Value Chain	
Agricultural production	
	Cropping activity
	Livestock activity
	Other agricultural production
	Agricultural supply activities
Manufacturing and processing of food products	
	Transport storage
	Wholesale retail
	Hospitality (restaurants, etc.)
Household consumption	
	Food consumed at home
	Food consumed at restaurants, etc.

While other parts of the value chain are important and may be used as starting points, it is the production processes at the farm level that provide the most useful point of departure. Describing the value chain thus commences with the production of agricultural outputs including crops and livestock. While potentially applicable in other primary production contexts, at this stage the focus excludes forestry, fisheries and aquaculture activity, except to the extent that this takes place in conjunction with agricultural activity (for example, in rice-fish farming systems).

Within the context of this boundary for agricultural production, it will be relevant to identify different types of producers (subsistence, small scale, commercial), different commodities, different production systems (e.g. intensive, extensive) and different locations, for example based on agro-ecological zones. Understanding these features will be highly relevant in comparisons between impacts as assessed by different studies.

The eco-agri-food value chain moves in two directions from the farm level. The first direction concerns those businesses that supply goods and services to agricultural producers. Key industries in this part of the chain include water suppliers, manufacturers of fertilizers, pesticides, seeds, animal feeds and medicines, etc., and energy suppliers (of electricity and fuel). For each of these businesses the Evaluation Framework encompasses measurement of their output, value added and other economic flows; their production of outputs; the inputs of water and energy; and potentially the associated outcomes associated with these industries, i.e. changes in their stocks of produced, natural, human and social capital. For ease of exposition, these supplying industries are presented as being within the agricultural production sector as one top-level part of the value chain.

This part of the value chain will also encompass connections between agricultural producers, for example farmers growing fodder crops to support livestock production. Depending on the analytical questions of interest and data availability, these different sub-parts of the agricultural production sector can be separately identified.

It is possible to envisage that the value chain for farmers might extend to include those ecosystems that supply ecosystem services as inputs to agricultural production. While possible in an accounting context, for the purposes of the TEEBAgriFood Evaluation Framework, the value chain is limited to connections between economic units, including households.

The second direction concerns the movement and transformation of agricultural output from the farm gate toward household consumption. The value chain in this direction includes the subsequent stages presented in **Table 6.2** (above) namely:

- Manufacturing and processing of food products
- Distribution, marketing and retail
- Household consumption

The concept of household consumption aligns with the definition of consumption in the System of National Accounts and hence covers purchases of food for consumption within the household, purchases of food supplied by restaurants and the hospitality industry more generally, and consumption of food grown at home (on "own-account").

Analysis of household consumption will be supported by breakdowns of consumption by income group, gender, age, types of food and diets. In particular, this detail will support analysis of the impacts of consumption on human health. In some cases, it will be relevant to consider the extent to which governments and international organizations purchase food on behalf of households or otherwise manage the supply and distribution of food to particular population groups.

As noted in the discussion of production and consumption, in making the connection between agricultural production and human health it will be relevant to consider multiple sources of food, e.g. imports of food, at least in cases where the population group of interest is not self-sufficient in food production. In understanding the flows of food products through the value chain, imports may need to be recorded at different stages including as imports of raw materials, through various stages of processing and on to distribution chains.

In keeping with the general "cradle-to-grave" philosophy of TEEBAgriFood, the value chain does not end with final consumption. It also includes recording the flows of food losses and waste that are associated with food production and consumption. The recording of losses and waste should take place at all stages of the value chain, and should highlight the role of the waste management industry in collecting and managing this flow.

In practice, the description of, and boundaries between, the different stages of the value chain should be aligned with the descriptions that underpin the collection and presentation of economic statistics in the International Standard Industrial Classification (ISIC). This classification (or national variants) is used by countries around the world and is the basis for the compilation of input-output tables that are a fundamental source of information for economic modelling. Data on employment and the labour force (and hence human capital) and also on environmental stocks and flows (following the SEEA) are also presented according to the ISIC. Alignment of the TEEBAgriFood Evaluation Framework with the definitions in these core datasets thus provides the strongest basis for the integration and comparison of data across countries and provides a consistent means of benchmarking at the corporate level.

6.4 APPLYING THE FRAMEWORK

The TEEBAgriFood Evaluation Framework intends to be useful to a range of stakeholders, including policymakers, farmers, businesses and citizens groups, and regarding a range of different issues, such as the effects of climate change, urbanization, and dietary change. This section introduces some potential applications and entry points to the Framework. It also presents steps that can be followed to undertake evaluations and places analytical tools in context. Finally, this section describes some remaining considerations relevant to the application of the Framework.

While it has been developed and discussed by experts, it must be recognised that the Framework described here represents a starting point in the development and implementation of more comprehensive and universal assessments of eco-agri-food systems. It should be expected that, over time, as this version of the Framework is tested in different settings, and as the theory underpinning integrated measurement frameworks expands, there will be revisions that take these developments into account.

6.4.1 Applications and entry points

The Framework is intended for use in an interdisciplinary manner, where the questions to be analysed, the options to be compared, the scale, scope, and most relevant variables can be determined before the appropriate assessment and valuation methods are selected. This section presents some of the potential applications and entry points for the TEEBAgriFood Evaluation Framework. Practical demonstrations of the ways in which the Framework may be applied are provided in Chapter 8.

Families of applications

To portray the potential applications of the TEEBAgriFood Evaluation Framework, five families of applications have been defined – agricultural management systems, business analysis, dietary comparison, policy evaluation and national accounts for the agricultural sector. The intention is that the Framework provides a common articulation of different eco-agri-food systems and hence can be used to support all of these applications, as shown in **Figure 6.6**. This intention mirrors the largely established situation for macroeconomic statistics where multiple applications are based on a single framework of data presented in the national accounts covering the full range of industries, sectors and countries.

In practice, it will be some time before this ambition can be seen as standard and indeed the evidence from the assessment of current examples in Chapter 8 highlights the degree of variation in approach that currently exists. Nonetheless, the TEEBAgriFood Evaluation Framework sets this ambition to provide a goal and rationale for future measurement and development.

As far as possible, the elements of the Framework have been defined in such a way as to be compatible with international statistical standards and guidance. Therefore, in the application of the Framework there is the potential to build strong partnerships with relevant statistical and technical agencies. The alignment of measurement with analysis within a single framework also enhances comparability of assessments and encourages more extensive and open dialogue among all stakeholders. For instance, the descriptive elements of the Framework represent a means by which information and data on progress towards the SDGs can be collected and organised.

Perspectives of different stakeholders

From the perspective of **governments**, it is clear that the policy landscape interacts with eco-agri-food systems in various ways such as in the case of land use and spatial planning, import/ export regulations, subsidies and taxes, and investments in agricultural research and development. All of these factors influence the way in which we produce, process, distribute and consume food (Rosegrant *et al.* 1998; Mogues *et al.* 2012)[10]. It is envisaged that central and local governments will be able to use the Framework in conjunction with related measurement and analytical tools to account for a complete range of costs and benefits for various public investments and expenditures across different farming systems. In particular, the Framework supports government incorporation of agricultural outcomes together with associated costs and benefits related to human health, GHG emissions, ecosystem functioning and other public goods. Further, the Framework provides a means to consider broad, systemic policy challenges such as climate change and urbanization.

Also, the Framework supports examination of the potential influence of eco-agri-food systems within development agendas, in particular the United Nations Sustainable Development Goals (SDGs) (UN 2015). Certain eco-agri-food systems generate greater positive impacts than others, for example, in relation to food security, employment and income generation, social cohesion, and conveying working capital to women. Since the Framework identifies these types of outcomes and evaluates the associated impacts on wellbeing, it can help to highlight entry points for enacting agricultural policies that contribute to these development goals.

Farmers can use the Framework to both understand and demonstrate their role beyond food production – for example, in preserving traditional knowledge and landscapes, contributing to food security, and supporting other allied sectors. Farmers can also use the Framework to demonstrate how changes in other sectors, such as the energy sector, would impact their farms and businesses, and not only in economic terms. This evidence can then be used to influence policy makers or raise awareness around the importance of farming activities.

In terms of farm management, the Framework may help with information gathering to better support more sustainable farm practices and to improve reporting on outcomes at the farm level for certification and compliance purposes. Finally, particularly with respect to ecosystem services, the data on ecosystem services recorded in Framework can underpin the development of markets in ecosystem services and/or the development of payments for ecosystem services (PES) schemes. Objectively measuring flows of ecosystem services, especially water regulation, carbon sequestration and sediment retention at the farm level can help convey the importance of these services and the role of farmers in supplying them.

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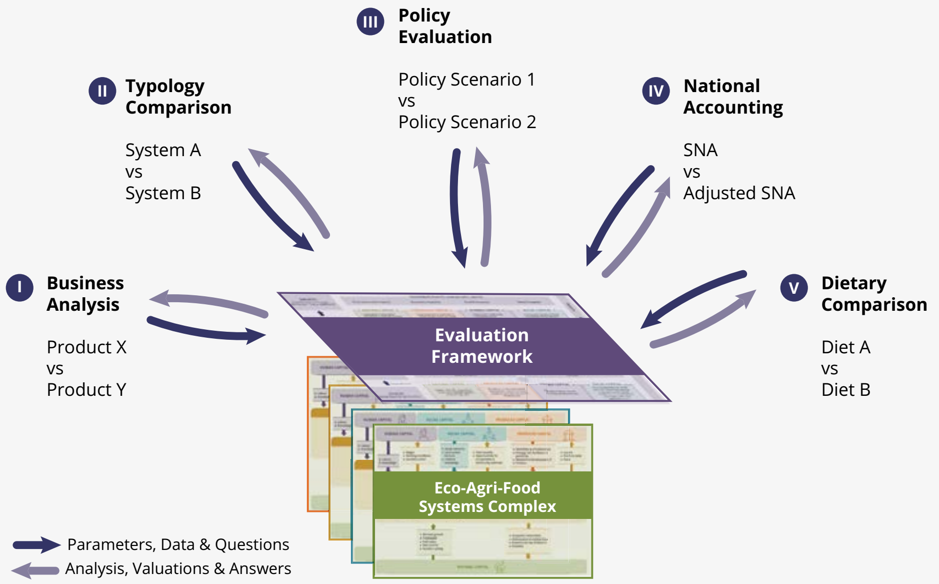
[10] For example, Rosegrant *et al.* (1998) analyze time series (1969-90) data from Indonesia for rice, maize, cassava and soybean-demonstrating that 85 per cent of the growth in rice, 85 per cent growth in maize, 93 per cent growth in cassava, and 71 per cent growth in soybean crops can be attributed to research, extension, and irrigation investment while remaining by output, input, and factor price changes (Mogues *et al.* 2012).

Figure 6.6 Applications of a universal evaluation framework (Source: authors)



Businesses, particularly agri-businesses and the food and beverages industry, face environmental challenges and changes in social expectations which present various risks and opportunities - operational, regulatory, reputational, market and product, and financing. Describing and accounting for contributions to wellbeing across their value chains using the Framework can allow businesses to better identify these risks and opportunities, and to take action. For example, businesses can use the Framework to determine environmental, health and social sustainability criteria in purchasing and sourcing decisions.

Citizens and consumer groups working in domains of health, food safety, and environment can use this Framework to assess food choices, organize information to hold public and private decision-makers accountable, highlight and encourage community and citizen engagement in local farming, and support production approaches that generate net positive impacts. An entry point for consumer groups may be to assess a particular food product. Here an assessment would aim to understand the extent to which the output from a particular farm (and associated agricultural practice), group of farms (e.g. in a region) or of a specific commodity has positive and negative impacts across the economic, social and environmental domains. Other assessments might focus on consumption perspectives considering current or ideal diets, or specific dietary components, such as protein.

6.4.2 Basic steps in applying the Framework for evaluation

This section presents the basic steps in applying the Evaluation Framework. As discussed earlier, the potential to describe eco-agri-food systems in terms of stocks, flows and outcomes allows all stakeholders, in their particular context, to assess a given eco-agri-food system in its totality, understand the material impacts and contextualize the analysis. Annex 6.1 provides a summary of how the Framework may be used, along with examples of the elements that may be part of an assessment. The annex may also be considered a standalone document since it also recapitulates the rationale and scope of the Evaluation Framework discussed in earlier sections of this chapter.

The analytical approaches described in Chapter 7 involve a comparison of different eco-agri-food systems in terms of their net contribution to human well-being in monetary terms. In concept, this approach can be applied relatively readily for economic, health and environmental impacts, noting a range of practical measurement challenges. However, in the space of social impacts the application of value addition is not possible. Thus, to provide a comprehensive analytical approach, value addition should be combined with other techniques, such as multi criteria analysis (see Chapter 7), to consider the overall contribution to human wellbeing.

To apply the Framework there are seven steps and associated decision points that should be appropriate for any assessment. These steps are depicted in **Figure 6.7** and described below.

1. Determine the purpose of evaluation

Different stakeholders, including government agencies, farmers and rural communities, businesses and civil society, will have different purposes for using the Framework. To facilitate exchange and dialogue it is important that the organisation or stakeholder leading the assessment is clear about the questions of interest and the anticipated role that the assessment will play.

2. Determine the entry point and spatial area for assessment

In determining the purpose of the evaluation, questions concerning the entry point and spatial scale for the analysis will inevitably arise. By entry point, it is meant that the evaluation must start from a particular point or perspective of eco-agri-food systems. Generally, the entry point will relate to a specific area of policy, business or research interest and will vary depending on the stakeholder. Examples of entry points for government include: agricultural production of a single commodity, sources of food waste, GHG emissions, obesity and water scarcity. For business, example entry points include analysis of sector and industry performance, value chains for a specific company and activities of individual business divisions. In addition to determining an entry point, the spatial area and scale of analysis needs to be considered. Evaluation might be undertaken at a global, regional, national, sub-national or community level, or for particular water catchments, climatic zones or soil types, or other combinations of spatial areas.

3. Determine the scope of the value chain

Determining the entry point provides the basis for determining how many parts of the value chain – upstream and downstream – are to be included in the evaluation. The intent in the design of the Framework is that no matter what part of the value chain is being evaluated, it should be possible to understand the linkages to other parts of the same value chain. The use of consistent language and measurement boundaries to define the value chain is central to this design feature.

In practice, the use of different datasets and methods will mean that alignment between evaluations will not be straightforward. Nonetheless, the ideals of the Framework will provide a common reference point for comparison. In determining the scope of the value chain, it will also be important to map out the likely spatial distribution of the value chain to ensure that all relevant connections are recognised and informed choices can be made on the appropriate scope of the evaluation.

4. Determine the appropriate focus on specific stocks, flows, and outcomes.

Depending on the type of question under consideration, it may be relevant to focus more heavily on particular types of capital: for example, consideration of water related questions will likely involve a more in-depth assessment of natural capital, and related flows, outcomes and impacts. As a general starting point however, it will be relevant for all evaluations to work through the relevance and materiality of the different stocks, flows, and outcomes to provide a rationale for their inclusion or exclusion.

Of particular interest in the context of TEEBAgriFood are stocks of natural capital and associated flows of ecosystem services on which eco-agri-food systems are dependent. It is likely that a degree of iteration will be required to ensure a coherence and alignment within the evaluation itself. In effect, discussion of each of these different components of an evaluation facilitates a comprehensive description and enables different evaluations to be placed in a common context.

5. Select evaluation technique for assessing impacts

The first four steps provide a complete framing for an evaluation project but it remains necessary to describe how evaluation of impacts will be undertaken. For TEEBAgriFood, the focus is on a value-addition based approach to assessing impacts as contributions to human well-being. Chapter 7 provides a thorough description of the value addition approach and also an introduction to a range of other evaluation methodologies, such as life cycle assessment and value chain analysis, and various modelling tools and techniques including partial and general equilibrium models and system dynamics. Generally, these other approaches will focus on parts of an eco-agri-food system rather than being comprehensive in scope. In that sense, the Evaluation Framework can support understanding the differences between results derived from different methods by providing a common framing for comparison.

As discussed in detail in Chapter 2, and as presented in the Framework, eco-agri-food systems are dynamic in nature, with numerous interacting parts. Any robust evaluation therefore should take a systems view. This is discussed further in the key considerations section below, and Chapter 7 discusses the types of tools that can be used to take a systems view.

6. Collect data and undertake evaluation

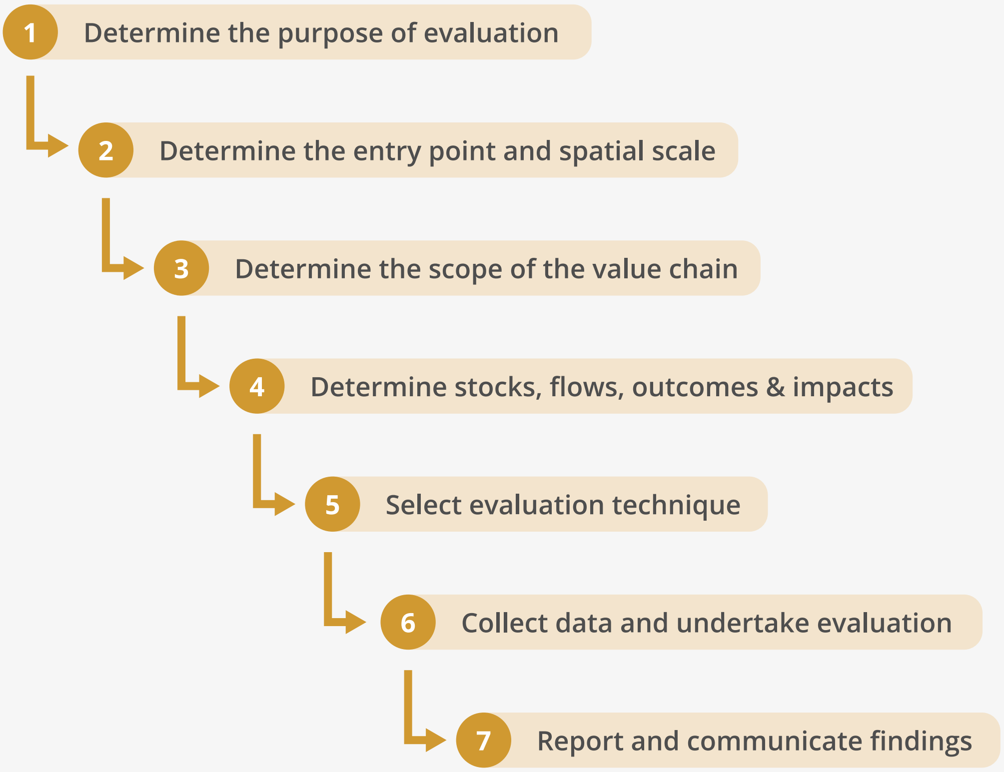
Although summarized here in one step, the likelihood is that most effort will be placed into this part of the evaluation process. It is essential however to complete steps 1-5 so that the actual collection of data and evaluation is completed with a clear context and goal.

There is a significant risk that evaluations are completed on the basis of only the information that is readily available, in effect meaning that the framing of the assessment is determined retrospectively. This risk must be actively managed. It may be that, in practice, evaluations must be limited due to a lack of data. Nonetheless, by completing steps 1-5, the implications of a lack of data can be understood and can provide a motivation for identifying and filling information gaps.

7. Report and communicate findings

Communicating the results of the evaluation exercise should be seen as an essential part of the process and not an after-thought. Further, since it is anticipated that these evaluations will involve multiple sectors and stakeholders, it is appropriate to see this final stage as the culmination of an ongoing process of engagement and discussion. Particular note should be taken of the need to develop a range of outputs to suit different audiences including politicians and business leaders, technical experts, farmers and local communities and the media. The reporting process should include providing a clear expression of the context and framing for the evaluation; the Framework should provide the rubric for such expression.

Figure 6.7 Steps in applying the TEEBAgriFood Evaluation Framework (Source: authors)



6.4.3 Key considerations

The Framework presents a universal set of elements that should be considered for a comprehensive assessment. It also provides multiple entry points and a consistent basis for evaluation using value addition, thus allowing it to be used for a diversity of purposes and audiences. However, given the complexity and diversity of eco-agri-food systems there are several considerations to keep in mind when employing this Framework.

Spatial and dynamic considerations

Key challenges arise from the fact that agricultural systems are dynamic, with components that change and influence each other over varying spatial and temporal scales. The components of the Framework – the various stocks, flows, outcomes and impacts - do not exist or function independently of each other. For example, in considering stocks, the state of natural capital may have implications for human capital – e.g., water scarcity can impinge negatively on human wellbeing. Similarly, human capital in the form of traditional knowledge of seed saving or livestock rearing can maintain stocks of genetic diversity, thereby enhancing stocks of natural capital. This can in turn have implications for resilience.

Further, flows may interact with each other – several ecosystem services are intermediate flows that support final ecosystem services. For instance, regulation of freshwater flows is an intermediate service that impacts the final provisioning of agricultural output. Some of these interactions may also be “feedback loops” – water scarcity can impact yields, but also impact human capital, which can in turn reduce labour inputs into the farm, further reducing the yields, and so on. In some analyses, these connections are referred to as leakages, for example where “positive” environmental actions to increase riparian areas within one farm system have an on-balance negative impact from a broader perspective as other farms clear land to maintain the level of food production (assuming constant productivity per hectare). In all cases, the description of the various feedback loops and leakages will be based on a range of assumptions and experiences. It is thus fundamental for informed decision making that these connections and relationships are recognized, captured and understood – something that the Framework supports and that a complex systems analysis helps to identify and model.

There are however two additional dimensions that need to be kept in mind. The first of these relates to time. There can be flows that are part of the system that, over time, reveal themselves or take effect as changes in stocks. For instance, nutrient runoff from a farm to a water body may not lead to eutrophication if the levels of runoff are within ecological thresholds, allowing for dissolved oxygen to be replenished. Over time however, if the ecological threshold for eutrophication is reached, fish kills and depletion of aquatic life may result. Therefore, once the natural or human capital outcome of interest is established (see previous section on entry points), scientific literature can help determine appropriate time horizons to consider. For a natural capital outcome, the appropriate time scale may be informed by the type of farm or ecosystem. Different thresholds apply depending on for instance, the type of water body and the transport pathways for the pollutant. Similarly, if a food and beverage company is assessing its operational risks from climate change, it should account for appropriate time horizons for each particular environmental risk – such as water scarcity, desertification, or sea level rise. Scientific literature can guide these choices as well.

The second dimension is that of space. Here, it is important to understand that the spatial scale appropriate for assessing biophysical stocks and flows may be different from the scale at which stocks and flows would be assessed from an economic perspective, for the same product. For example, hydrological services are often measured at the watershed level, and this is appropriate if focus is on an individual food manufacturer’s use of water in a given location. However, as an evaluation widens to consider additional components of the Framework and additional parts of the value chain, it will be necessary to integrate additional and potentially higher spatial scales. For example, if much of the labour employed in a factory comes from outside the watershed, but working conditions and employment generation are attributable to the factory’s location, it will be necessary to consider how to reflect changes in the human capital base outside the watershed. Moreover, if the production from the watershed is exported to another country, the health benefits or costs of consumption will have their own sets of impacts on stocks of human capital outside the producing country (Bassi 2016). Here too the purpose of the evaluation and mapping of the value chain should guide the selection of appropriate spatial scales.

Risk and resilience

From a systems perspective, the concepts of risk and resilience are central if often difficult to quantify. The assessment of these concepts in the context of the Evaluation Framework is most directly considered in relation to the different capitals. In essence, many issues concerning risk and resilience, for example, the risks of climate change and the resilience of local communities, can be discussed reasonably readily in terms of different capitals and their capacity to provide services and associated contributions to human wellbeing into the future.

By framing risk and resilience in the context of the four capitals, as is possible to clearly relate issues of risk and resilience to observable measures of stocks, flows and outcomes. Further, in a situation of perfect information, the degree of risk faced by different stakeholders and their level of resilience will be embedded in the prices derived for the measurement of impacts in a value additions approach. Since information is not perfect, it is necessary to be clear about the assumptions being made in valuation and to provide information about the extent of exposure to risk and the degree of resilience of a given eco-agri-food system whenever possible.

Commensurability

The next key consideration is that of commensurability of the Evaluation Framework components. The Framework allows assessment of both economically invisible and visible flows. Various economically invisible flows however can ultimately become economically visible. For instance, consider an almond farm and an adjoining forest. The pollination service provided by the forest is an economically invisible flow that has a bearing on the final provisioning of almond yields. While pollination services are not recorded in standard reporting, the yields are, and the Framework identifies and incorporates assessment of both of these flows. But why bother examining pollination services from the forest when their value is implicitly captured in the almond yield? The reason is that recording only yields does not provide us with any information on the future ability of the ecosystems to support existing yields, or to understand the relative value of the forest as a stock of natural capital. This information can be critical for resource management. Therefore, it is important to examine both ecosystem services and yields although it would be incorrect to simply add the value of these flows together to obtain a total impact, since that would reflect double counting.

Since the Framework includes stocks and flows of that are very different in nature – economic flows and cultural flows for example – sometimes it may not be possible to aggregate even if it would seem useful for reporting purposes. As mentioned earlier, the use of multi-criteria analysis is important when applying the Framework.

Uncertainty

In measurement, it is also necessary to take uncertainties into account. This is especially true when establishing causal relationships between two variables in evaluating a specific impact. For example, attributing obesity to a particular diet is not straightforward – there are various factors such as genetics, lifestyle choices, and access to food that impact an individual's or a community's health outcomes. Assessing these relationships should take these uncertainties into account. Similarly, while dose-response functions describe the changes in an organism caused at varying levels of exposure to certain foods or environmental stressors, they cannot take account of all local environmental or social factors, and often are accompanied by uncertainty measurements.

A particular set of uncertainties emerges in the assessment of capital since it is necessary, in assessing, for example, the sustainability and capacity of capital, to consider the likely future generation of services and benefits - a process prone to forecasting errors. A specific challenge in this context is incorporating the effects of climate change on the eco-agri-food system.

More broadly, consideration of uncertainties must extend to unknown outcomes and impacts arising from past and current patterns of production and consumption. For example, the health impact of genetically modified crops is an area of considerable uncertainty at present (Hilbeck *et al.* 2015). The existence of uncertainty on the basis of current knowledge inherently supports the application of the precautionary principle in decision-making (TEEB 2010a).

6.5 CONCLUSIONS AND PATHWAY FORWARD

This chapter has described a comprehensive and universal framework for the assessment of eco-agri-food systems, applicable for multiple purposes, different stakeholders coming and a variety of entry points. The accessibility of the Framework to all stakeholders in eco-agri-food systems is essential in promoting and embedding a common understanding of the challenges to and the viability of alternative pathways and solutions. As a comprehensive framework, the TEEBAgriFood Evaluation Framework takes into consideration all forms of capital that underpin economic and human well-being – produced, natural, human and social capital. The Framework also recognises all of the relevant flows and outcomes – visible and invisible; positive and negative. The comprehensive nature of the Framework provides a basis to meaningfully describe and compare different eco-agri-food systems; understand the materiality of different stocks, flows and outcomes in different systems; and provide a standardised context for analysis.

To meaningfully evaluate different eco-agri-food systems, it is also necessary to find a common basis for assessment. The analytical approach proposed in TEEBAgriFood utilises comparisons based on contributions to human well-being. Measurement of these contributions can be standardised using the concept of value addition for many aspects of eco-agri-food systems in terms of assessing impacts on economic, health and environmental impacts. To encompass social impacts and to incorporate risk and resilience into an evaluation, additional analytical techniques will need to be used, albeit still within the common framing of contributions to human well-being. Chapter 7 describes relevant techniques.

Importantly, the TEEBAgriFood Evaluation Framework builds on the latest understandings of integrated measurement and evaluation, particularly accounting frameworks and integrated systems thinking. Of course, many integrated decision-making challenges remain. However, in providing a comprehensive scope and universally applicable framing, the Framework provides a strong platform for advancement.

Four particular areas of research merit further investigation. First, the Framework uses accounting principles as its basis. While these principles are well established, their full application to areas such as social capital and accounting for biodiversity requires additional discussion and development.

Second, there is a need for ongoing discussion on the development of statistical standards, including terms, definitions and classifications, to support production of coherent data sets. When working in an integrated information space, i.e. across data silos, the need for such harmonisation becomes apparent very quickly. At the same time, relevant statistical standards have been developed in many areas of the Framework and thus the challenge is to look for synthesis and integration.

Third, notwithstanding the potential to describe systems in terms of stocks and flows, there remains a broader challenge of recognising that eco-agri-food systems are nested spatially and also need to be considered dynamically.

Finally, research needs to continue towards bringing all of these parts together with an integrated analytical approach. The discussion in Chapter 7 presents the state of the art in terms of integrated analysis but greater understanding of specific aspects is needed, particularly in the social dimension.

Chapter 8 presents a range of case studies of evaluation of eco-agri-food systems with different entry points in terms of agricultural products, sectors (both public and private) and purposes. However, all of the case studies are partial in the context of the comprehensive approach described in the TEEBAgriFood Evaluation Framework. Testing of some complete case studies must therefore be a priority.

The TEEBAgriFood Evaluation Framework provides a strong basis for comprehensive assessment of eco-agri-food systems around the world. Applying the Framework gives stakeholders a means to extract and combine data from different data sets and supports discussion of the integrated challenges of the eco-agri-food system. It is only by revealing the reality of the full impacts of different systems that progress towards long-term, sustainable solutions can be made.

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CHAPTER 7

TEEBAGRIFOOD METHODOLOGY: AN OVERVIEW OF EVALUATION AND VALUATION METHODS AND TOOLS

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SUMMARY

Chapter 7 presents an overview of available evaluation and valuation methods and tools relevant to the analysis of dependence and impacts of various agricultural and food systems on human wellbeing. The market and non-market valuation tools and methods address to varying degrees the positive and negative externalities along the value chain of eco-agri-food systems. However, challenges emerge from the complexity of the systems, stemming from the temporal and spatial dimensions and management practices and value attribution across multiple ecosystem services. As decision making requires integration of economic values with other social and economic dimensions, the chapter presents an integrated systems approach, which helps in incorporating various dimensions together to evaluate the impact of various policies on the human wellbeing.

CONTENTS

FIGURES, BOXES AND TABLES

CHAPTER 7

7.0 KEY MESSAGES

- This chapter presents an overview of available evaluation and valuation methods and tools relevant for the analysis of dependence and impacts of various agricultural and food (eco-agri-food) systems on human wellbeing.
- The eco-agri-food system has undergone deep economic and technological transformation. As a result there have been a number of intended and unintended impacts on human well-being. These necessitate a careful evaluation of the associated external effects and the social, economic and environmental impacts.
- Several market and non-market valuation tools and methods can take into account the externalities along the value chain from the farm gate to the food plate of the eco-agri-food system. However, no single tool or model addresses all the needs of the stakeholders and effectively takes account of the complexity of the system analysed.
- Valuation methods can provide credible numbers but to do so they require a lot of data as well as information on the context, purpose and the assumptions behind the values.
- The challenges of valuation of agricultural and food systems arise from their spatial dependence, scale of occurrence of ecosystem services, temporal dimensions, management practices and attribution of values across multiple services.
- The transferability of values from one context to another is possible but requires extensive socio-economic and environmental information about the site where they were estimated and the site where they will be applied.
- Decision making does not depend only on economic values but also included wider dimensions. There are tools that can integrate the economic values into wider dimensions of policy making.
- The external impact of the eco-agri-food value chain is dynamically linked to economic and social impacts through positive and negative feedback loops. Thus the system has to be analysed and integrated as a whole, taking account of these dynamic factors.
- Use of a systems approach can support the integration of knowledge across fields and complement existing work by generating an assessment of the social, economic and environmental impacts of production and consumption, and by estimating strategy/policy impacts for a specific project/policy and for society.
- The scenarios of the systems approach can help simplify and understand the complexity of the eco-agri-food system, and evaluate the short vs. longer-term advantages and disadvantages of the analysed interventions.

CHAPTER 7

TEEBAGRIFOOD METHODOLOGY AN OVERVIEW OF EVALUATION AND VALUATION METHODS AND TOOLS

7.1 INTRODUCTION

This chapter presents an overview of evaluation and valuation methods and tools to assess the dependence and impacts of agricultural and food (agri-food) production, processing, distribution and consumption activities on supporting ecosystems and their services, and on human wellbeing. These ecosystems are an essential part of the asset base of a country or region, which includes produced, natural, human and social capital, as discussed in the previous chapter.

Whereas Chapter 6 described the TEEB Evaluation Framework and established *what* should be evaluated regarding the social, economic, and environmental elements as well inputs and outputs across the value chain, this chapter explores *how* to carry out the evaluation, making the distinction between (and presenting examples of) methods for the economic *valuation* of ecosystem services and disservices in both monetary and non-monetary terms. It also covers evaluation methods and *modelling* tools and techniques. The distinction between valuation and evaluation is explained in the next section. Evaluation and valuation methods can help in addressing for instance, questions such as:

1. To what extent can food security be improved through agricultural intensification, as opposed to expanding the area devoted to agricultural production, and in both cases, what are the external costs and benefits?
2. Organic farming and low external input agriculture are presented as alternatives to conventional farm management systems, which proponents claim will better protect the health of soils, plants and wildlife. What are the impacts of these practices on society?
3. Food production has multiple environmental impacts and ecological dependencies. What farm management systems and practices can ensure food security while reducing adverse environmental impacts? What are the synergies and trade-offs involved?

The chapter is structured as follows: the rest of this section explores the issues that need to be investigated. We introduce the concept of external costs in the context of agricultural systems. Section 7.2 explains the distinction between *valuing* the impacts of eco-agri-food systems and a wider *evaluation* of the systems as well as policies to make them more effective. Section 7.3 describes the different valuation methods relevant to the sector and discusses their strengths and weaknesses. Section 7.4 does the same for various evaluation methodologies. Section 7.5 discusses how different modelling tools can inform the evaluation process, while section 7.6 introduces the use of integrated modelling. Finally, section 7.7 provides a summary and concluding remarks.

7.1.1 Key Issues and factors in the selection of evaluation and valuation methods and criteria

Complexities in agriculture and food systems and the feedback with ecosystem services

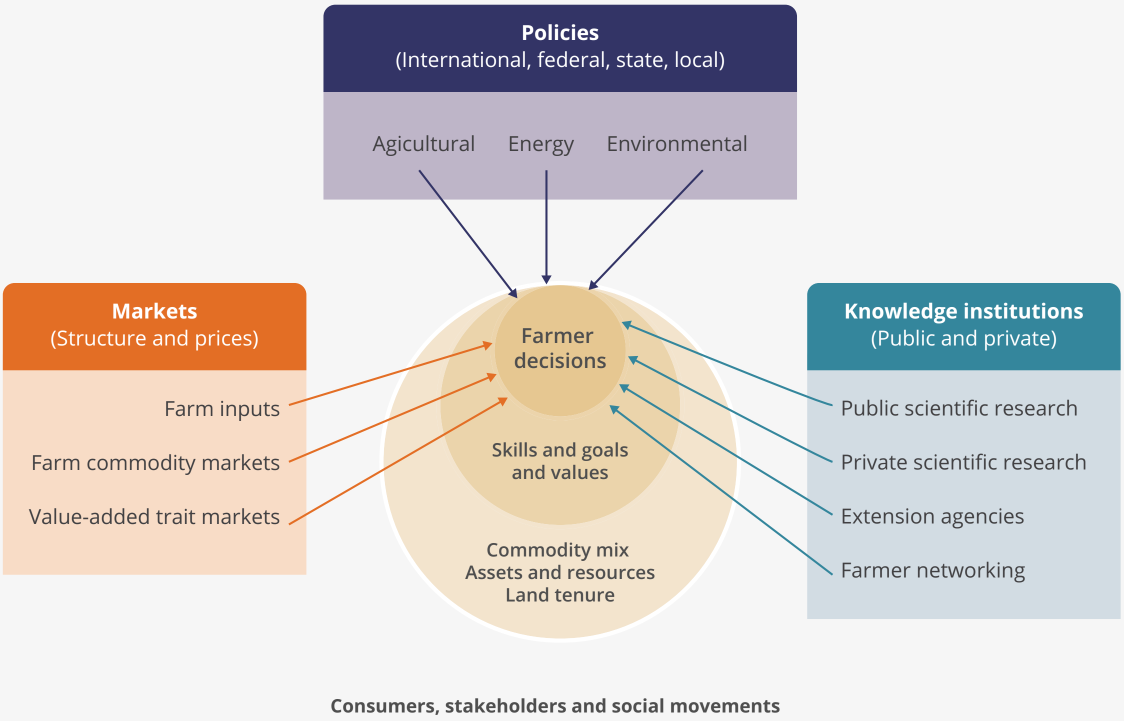
Agricultural systems, though managed to provide food, fibre and fuel, are unique in receiving and providing ecosystem services as well as generating disservices to other ecosystems (Swinton *et al.* 2007). Producers rely on ecosystem service inputs, which they combine with land, seeds, labour and technology to produce a range of valuable products, along with other ecosystem services and disservices, which vary in their effects on human well-being. For example, the quality of soil including the quantity of soil carbon is one of the key inputs necessary to generate a good yield but it is impacted by soil tillage, crop rotation practices, the level of organic inputs and erosion. The services from these ecosystems can also be seen as a return to the stock of natural capital. Changes in the expected flow of services arising from non-sustainable use, for example, will be reflected in a decline in the value of natural capital, which can act as a guide to the dangers of some eco-agri-food practices.

According to OECD (2000), the following risks are common to the agriculture sector: production risks (weather conditions, pests, diseases and technological change), ecological risks (climate change, management of natural resources such as water), market risks (output and input price variability, relationships with the food chain with respect to quality, new products) and regulatory or institutional risks (agricultural policies, food safety and environmental regulations).

Farms are managed ecosystems and their final output depends on the choices that the farmer or farm manager takes, and are linked to the farm's external environment, which depends on a range of natural, technological, social, economic and political factors (see **Figure 7.1**). Farm output not only depends on a farmer's own decisions but also on the actions of other farmers and consumers, policy-makers, general conditions of trade, etc. For example, if a farmer decides to plant eucalyptus trees on her land to sequester carbon for the offset market, this might lower the water table more widely. If a farm suffers from a sudden infestation of pests, a neighbouring farm is also at risk. The introduction of alien species or invasive plants can have detrimental effects on some native pollinators but in certain cases may support other native pollinators.

Decisions made by farmers, like those involving crop diversity, fertilizer and pesticide use etc., impact on the environmental quality of their land and beyond (Tilman 2002). These impacts from the agricultural production systems are transmitted by biological, chemical or physical processes and the external costs (and benefits) are not reflected in the price of goods in this sector. Usually the impacts are borne (or enjoyed) by society more widely and by people who may not be actually producing these impacts, which raises both efficiency and equity concerns. Pretty *et al.* (2000) describe five features of externalities from agriculture: 1) markets neglect many external costs and benefits; 2) they often occur with a time lag; 3) they affect groups whose interests are not always represented in decisions; 4) the identity of the producer of the externality is often not known; and 5) externalities can result in suboptimal economic and policy outcomes, including more output and higher levels of pollution (the efficiency concern). In many countries, farming has evolved to a state where it is often in conflict with environmental protection. The costs of agricultural externalities can be substantial, as shown by estimates made for Germany (Waibel and Fleischer 1998), Netherlands (Bos *et al.* 2013), UK (Pretty *et al.* 2000; 2005) and the USA, , (Tegtmeier and Duffy 2004). For losses of ecosystem services due to modernization of agriculture in Sweden see Björklund *et al.* (1999). A more detailed breakdown of the external costs in the UK from Pretty *et al.* (2000) is given in Section 7.4, where methods of valuation are discussed.

Figure 7.1 Drivers and constraints that affect farmers' decisions (Source: adapted from Reganold 2011)



7.2 THE NEED FOR VALUATION AND EVALUATION OF ECO-AGRI-FOOD SYSTEMS

As mentioned above, many of the ecosystem service dependencies and impacts of the eco-agri-food system are not fully captured in markets. Economic valuation tools can be helpful to quantify dependencies and impacts in monetary terms and make them more comparable to other things we value.

However, valuation alone cannot provide a complete picture; we need additional evaluation techniques to understand the relative merits of different actions, strategies, and policies. Different policies (e.g. subsidies or taxes, agricultural policies), resource allocations (e.g. how much water to use for irrigation) and production decisions (e.g. what type of crop rotation to implement) made by different stakeholders (farmers, policy makers, consumers) involve trade-offs for the economy, the environment and various stakeholders. Economic valuation methods can provide the data needed to evaluate such trade-offs. Evaluation techniques are then used to understand whether the benefits are worth the costs not only to society as a whole but also to groups of producers and consumers, while also assessing the wider social (particularly distributional), economic and environmental impacts of decisions.

Agriculture depends on ecosystem services as inputs as well as providing many ecosystem services (see **Table 7.1**). Food produced by farmers goes through stages, from land clearance and preparation, to planting, growing, harvesting, preparing products for the consumer market, consumption and final disposal of any wastes. At each stage, a number of economic impacts are generated, in the form of incomes to producers, wages to employees, tax revenues to the government or subsidies from the government, possible imports of inputs and exports of outputs and so on. Some of these impacts are captured through market transactions or flows of financial resources from one agent in society to another, while several other intended (positive) and unintended (negative) impacts on the economy and well-being are not captured. Some modern industrial food systems also pose health hazards for consumers, which are not appropriately valued.

For example, modern farming practices have improved livestock feed efficiency through the use of antibiotics. Less time is needed to bring animals to slaughter, reducing costs to the producer, improving profits and decreasing consumer costs. Similarly, antimicrobial products have improved prevention, control and treatment of infectious diseases in animals. Van Lunen (2003) reports that in the U.S., 52 per cent of total antimicrobials were used for the treatment of infectious diseases in animals, and 25-70 per cent of cattle received the drugs through feed. However, both of these technologies can pose significant health risks to humans and some countries have banned the use of antimicrobials for livestock production (Barug et al. 2006). These hazards were discussed in greater depth in earlier chapters.

It is important to consider eco-agri-food systems as a whole if effective strategies to internalize the externalities from ec0-agrif00d systems are to be designed and implemented. In much of the literature, each stage of the value chain is analysed separately. Partial exceptions include the work of Pretty *et al.* (2005; 2015), some life cycle assessments (Shonfield and Dumelin 2005, discussed in Section 7.5.2), and the propensity scoring method (Setboonsarng and Markandya 2015, discussed in Section 7.5.4).

There are positive and negative feedback loops across the whole value chain of eco-agri-food processes (FAO 2014). Changes have both backward and forward linkages with economic, environmental and social outcomes in other stages of the value chain. For example, a change in consumer preferences for organic food can affect the earlier food production and processing stages and create environmental and social consequences. Likewise, an increase in crop yields will have social and environmental impacts at the production stage as well as on levels of profits, prices, nutrition and consumption. Changes outside the eco-agri-food sector, such as an increase in the demand for biofuels, for example, may raise the price of land and increase crop prices. This in turn will have impacts on poverty and malnutrition at the production and consumption stages (IFPRI 2008; Gerasimchuk et al. 2012).

Some of the health hazards of eco-agri-food systems do not qualify as conventional externalities, particularly in the consumption stages of the process, such as over-consumption of products high in sugar and fats: consumers pay for the products and make a conscious decision to consume them without being obliged to do so. Nevertheless, such consumption is a social concern because of harmful effects on consumers, which impact publicly funded health services (Green *et al.* 2014). The term used to refer to such goods or activities is *demerit goods* or activities[1]. A demerit good is defined as a good which can have a negative impact on the consumer and society, but these damaging effects may be unknown or ignored by the consumer. There is a debate as to how much the government should control the availability of harmful products and what form such interventions should take. The opposite of a demerit good or service is a merit good or service – one whose consumption has wider social benefits (e.g. vaccinations, education). The notion of merit and demerit goods thus extends the concept of externalities.

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[1] For a definition of merit goods and demerit goods see Musgrave, 1987. Strictly speaking demerit goods are not externalities in the sense that their consumption harms a third party (e.g. if I smoke in my home with no one else around I am not generating an externality in the conventional sense, but I am consuming a demerit good insofar as overall social welfare is diminished by such consumption).

Table 7.1 Classification of Ecosystem Services from Agriculture (Source: EEA 2018)

Section	Division	Group	Class
Provisioning	Nutrition	Biomass	Cultivated Crops Reared animals and their outputs Wild plants, algae and their outputs Wild animals and their outputs Plants and algae from in-situ aquaculture Animals from in-situ aquaculture
		Water	Surface water for drinking Groundwater for drinking
	Materials	Biomass	Fibre and other materials from plants Plants, algae, animal materials for agriculture Genetic materials from all biota
		Water	Surface water for non-drinking purposes Groundwater for non-drinking purposes
	Energy	Biomass based energy	Plant-based resources Animal-based resources
		Mechanical based	Animal-based energy
Regulation and Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bioremediation by micro-organisms etc. Filtration/sequestration/storage/ accumulation by micro-organisms etc.
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation Dilution by atmosphere, freshwater, marine ecosystems Mediation of smell, noise, visual impacts
	Mediation of flows	Mass flows	Stabilisation & control of erosion rates Buffering & attenuation of mass flows
		Liquid flows	Hydrological cycle & water flow maintenance Flood protection
		Air Flows	Storm protection, ventilation and transpiration
	Maintenance of physical, chemical, biological conditions	Habitat and gene pool protection	Pollination & seed dispersal Maintaining nursery populations & habitats
		Pest & disease control	Pest control Disease control
		Soil formation & Composition	Weathering processes Decomposition and fixing processes
		Water conditions	Chemical condition of fresh & salt waters
		Atmosphere & Climate regulation	Global climate regulation by reducing GHGs Micro & region climate regulation
Cultural	Physical & intellectual interactions with biota/ ecosystems	Physical & experiential	Experiential use of plants, animal landscapes Physical use of land/ seascapes in different ways
		Intellectual & representative interactions	Scientific, educational, heritage/cultural, entertainment and aesthetic interactions
	Spiritual, symbolic interactions with biota/ ecosystems	Spiritual and/ or emblematic	Symbolic Sacred and/or religious
		Other cultural	Existence Bequest

A comprehensive assessment of agricultural and food system complexes taking into account all externalities from farm gate to the food plate, as well as impacts that are not strictly speaking externalities but constitute effects of social concern, requires market and non-market valuation of the dependencies, services and disservices provided by agriculture and food systems. Without valuation, we cannot understand the net benefits or net costs of an intervention. For example, a decision to ban neonicotinoid pesticides in the EU could lead to decline in agricultural yield, but is this good or bad (see Goulson [2013] for evaluation of this case study)? It may be good for insects and the pollination services (a public good/ public benefit) they provide to farming (not to mention their role in ecological health) but bad for yield and thus private profits (private costs). The question arises, is this ban worth the cost? Valuation tools allow for assessment of the impacts of a ban on production (negative) and the contribution to pollination (positive).

Section 7.4 reviews various methods and models that have been used to evaluate the agri-food system. No one model can address all the needs of different stakeholders and effectively account for the full complexity of the system, but using a systems analysis approach can support the integration of knowledge from across disciplines and shed light on the diverse social, economic and environmental impacts of production and consumption. In section 7.5, Systems Dynamic modelling is presented as a methodology that allows analysts to identify and anticipate the emergence of potential side effects, leading to the formulation of complementary policy interventions for improved resilience and sustainability. First, however, we review the various valuation methods available to assess the eco-agri-food system.

7.3 PRACTICAL METHODS FOR THE ECONOMIC VALUATION OF ECOSYSTEM SERVICES, DISSERVICES AND DEPENDENCIES IN ECO-AGRI-FOOD SYSTEMS

7.3.1 Economic Valuation

Farmers' dependencies on ecosystem services, their provisioning of ecosystem services and the impacts of agricultural practices on the wellbeing of people both on and off-farm follow several pathways. Some of these dependencies, outputs and impacts involve market transactions and can be quantified and valued in money terms while other dependencies do not involve such transactions and need different methods of valuation. This section reviews methods for valuing these non-market impacts and dependencies of the eco-agri-food system.

As noted, many ecosystem services are intangible and their role can only be inferred. For example, the nutrient cycling service of soil microbes cannot be directly experienced but food producers, through their experience, know that certain practices lead to better nutrient exchange and enhanced crop output. Similarly, some ecosystem services are more local in nature while others are global. For example, nutrient cycling is experienced only on farm, while aesthetic values are often regional, and carbon regulation is a global service. Ecosystem services most relevant to farmers, local communities and society at large may differ (Swinton *et al.* 2015). A key feature of many ecosystem services or disservices is that consumers/producers need not pay to benefit from the service, nor can they necessarily be excluded from consuming the output (e.g. if at a reasonable distance a farmer manages beehives for pollination, other farmers cannot be excluded from consuming the service provided by travelling pollinators).

The fundamental basis for valuing any goods and services – marketed or non-marketed – is the individual willingness to pay for them. The techniques discussed in this section utilize that base concept, although some methods may depart from the ideal due to lack of data[2].

Many studies have been undertaken to value the flow of services from ecosystems,3 much of which was summarized in TEEB (2010).

The methods used to elicit estimates of ecosystem services cover the whole range of valuation techniques used in environmental economics. **Table 7.2** summarizes different techniques used in a comprehensive review of valuation studies by de Groot *et al.* (2012). One main method used is direct market valuation, notably direct market pricing. Direct market valuation methods include market pricing, market based payments for environmental services, factor income/production function methods and the cost based approaches. Where data from actual markets are available, direct market, valuation approaches are preferred. They are most often deployed for valuing

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[2] One example of an approach that deviates from willingness to pay is surveys of happiness, which seek to measure wellbeing using a subjective happiness scale. This approach has been used in recent years to track progress in a number of areas, but there are few cases relating to ecosystem services. For a recent example of the happiness approach see Tsurumi and Managi (2017).

[3] See www.es-partnership.org for access to a wide range of databases linking to such studies, as well as the Environmental Valuation Reference Inventory (EVRI 1997), Cost of Policy Inaction Valuation Database (Braat et al. 2008), ENValue (2004)ValueBaseSwe (Sundberg and Söderqvist 2004), and work done by de Groot et al. (2012), McVittie and Hussain (2013) and Costanza et al. (2014).

provisioning services but are also frequently used for habitat services and cultural services. Cost-based valuation methods include: avoided cost, restoration cost, and replacement cost4. They are most often used to value regulating services (water regulation, erosion control, air quality regulation, human disease regulation). However, only a sub-set of ecosystem services can be valued using direct market valuation methods.

However, in several cases, direct market data is not easily available or markets do not exist. In such cases, the revealed preference or stated preference methods are used. The revealed preference methods consist of hedonic pricing and travel cost methods where individuals reveal their preference through their observed behaviour in the surrogate markets (e.g. through travel costs to visit agricultural landscapes, paying a premium price for buying a property with good views etc.); these are used mainly for valuing cultural services (recreational or amenity values). Finally, stated preference methods consist of contingent valuation, conjoint choice and group valuation and uses hypothetical (or simulated markets) to elicit values through willingness to pay to obtain the ecosystem service or willingness to accept as compensation for losing access to an ecosystem service.

The approach is typically used for valuing habitat and cultural services (Pearce *et al.* 2006). Stated preference techniques are the only way to value some ecosystem services (like biodiversity) when the ecosystem services cannot be valued through markets or surrogate markets. The categories given in **Table 7.2** cover a wide range of services with different methods of elicitation of values. Some might question whether the services valued using stated preferences or indirect valuation methods of revealed preferences are as “real” (i.e. since they are not based on actual transactions, do they represent the true underlying preferences of the respondents) as those obtained using market methods. Evidence shows that non-market methods for valuation, when used with care and following the best available techniques, do provide credible numbers that can be compared to those obtained from market transactions.

When choosing the economic valuation technique appropriate to a given application, the following considerations should be noted:

1. There is spatial variation in the ecosystem services provided by (or to) agriculture, which depend not only on farm management practices but also on the landscape attributes (e.g. agricultural land next to a tropical forest is different from farm land adjacent to grasslands). The valuation of agricultural and food systems is challenging due to this spatial dependence.

2. The level of ecosystem services/disservices provided by (or to) agriculture is also dependent on the management practices adopted by producers, which in turn depend on prices of other inputs. Thus, it is difficult to generalize or transfer values from one site to another without complete information.

3. The scale at which particular changes in ecosystem services occur is very important. While changes in soil carbon affect farm output and occur at the level of farm and have implications for profitability for the farmer, soil erosion can also have impacts downstream and affect people more broadly. Thus the value of a particular ecosystem service to the farm and to society need not be the same.

4. There is a temporal dimension as well, owing to time lags in both provision of ecosystem services as well their impacts.

5. There is a risk of double counting. For example, grassland diversity improves crop yield due to increased abundance of insect pollinators (leading to increased food production). In this case the grassland diversity results in improved pollination services leading to higher crop yields. Here pollination is an intermediate service. Thus ecosystem services from grasslands and ecosystem services from agriculture cannot be added separately. Not all categories of regulating benefits, however, constitute double counting. Care is needed when assembling total values and it should be noted that the total figures may contain some double counting).

7.3.2 Direct Market Value Approaches (Primary Market Based Approaches)

Market value approaches to measuring agricultural output rely on the value of ecosystem services that are directly sold in markets. For example, the provisioning services from agriculture, such as food, fuel and fibre, can be relatively easily quantified based on market prices (although price distortions arise due to uncompetitive markets or taxes or subsidies). The benefit from any project (say soil conservation through terracing), if it results in increased yield, can be measured in terms of the increase in consumer surplus or producer surplus realized through the output sold in the market5.

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[4] Replacement cost is not a desirable standalone method of valuation as it is not necessarily based on the willingness to pay for the service. In many instances it is used as a first approximation and so has been included here.

[5] The consumer surplus is the difference between what a person is willing to pay for something and what she actually pays. The producer surplus is the difference between the revenue a producer receives and the cost of producing the good or service.

Table 7.2 Methods used to value ecosystem services (per cent (%) of studies that use different values for a given ecosystem service) (Source: adapted from de Groot et al. 2012)

Ecosystem Services	Direct Market Values	Cost Based Methods	Revealed Preference	Stated Preference
Provisioning	84%	8%	0%	3%
Regulating	18%	66%	0%	5%
Habitat	32%	6%	0%	47%
Cultural	39%	0%	19%	36%

Note percentages sum from left-to-right. Where they do not sum to 100 per cent methods were not stated clearly

Thus the value of soil conservation can be estimated in terms of the reduced costs of production (e.g. reduction in fertilizer costs). Some of the methods of ecosystem service valuation that fall under direct market value approaches include measurements of Production Functions and Dose Response Functions, analysis of Averting or Defensive Expenditure, Residual Imputation methods, and various cost-based techniques (Replacement/Restoration/Cost Savings). The rest of this section describes each of these approaches in turn, including their uses and limitations.In the section below, the different methods of valuation are described further and their potential application to eco-agri-food systems is discussed.

Production Function

Measuring the value of an ecosystem service involves measuring several independent inputs, which are combined and transformed to produce a single commodity or multiple agricultural commodities. As several of these inputs are biophysical and do not have market values, a way to estimate the value of these inputs is to use the production function method. The production function is, by definition, the technical relationship between outputs and technically feasible inputs. The farmer combines a range of inputs including land, labour, seeds, capital, soil, technology, fertilizers, pesticides, water, pollination services and other environmental variables to produce output. Different combinations of inputs are possible to produce a given level of output (some are fixed inputs and others are variable). Some of these inputs are complementary and some can be substituted (consider fertilizer and soil quality: if soil is of good quality, one can use less fertilizer). The production function gives us the maximum attainable output from a given combination of inputs under efficient management. Inefficient management reduces output from what is technologically possible.

The first step in estimating a specific production function for the inputs and outputs associated with a farm or set of farms for example involves the choice of relevant inputs such as labour, capital, purchased inputs (fertilizers, pesticides), environment inputs (quality of soil, water, climate etc.), management practices, and socio-economic factors that represent the farmer's knowledge, ability and attitude towards producing output. For inputs that are substitutable, several combinations might give the same level of output. Substitutability depends on elasticity, which is estimated from the parameters in the production function. The second step involves choosing the algebraic form of the production function linking inputs to outputs. The appropriate production function chosen depends on the nature of inputs, their substitutability and their relation to output6. The third step involves choosing an appropriate econometric technique for estimating the coefficients of the production function that quantify for example, the relationship between each input and the output. The production function gives the relative contribution of each input to the output. Any changes in the inputs leads to changes in crop yields, and maintaining the output at a constant level requires corresponding changes in the quality of input as well.

This approach is very useful in understanding the value of agricultural resource investments (or of their absence), the economic impact of land degradation (soil erosion, for instance) or measuring the value of conservation practices (terracing) etc. See **Box 7.1** for an illustration of how the production function can be applied.

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[6] Commonly used production functions are the Cobb-Douglas production function, linear production function, Fixed-proportion production function, Constant Elasticity of Substitution (CES) production function. In the linear-production function, the inputs are perfect substitutes. In fixed-proportion production function, the inputs must be combined in a constant ratio to one another (the inputs are complements). The Cobb-Douglas is intermediate between linear and fixed proportion production function (assumes unitary elasticity of substitution) and is most commonly used. The linear production function, fixed proportions production function and Cobb-Douglas are special cases of CES production function.

Box 7.1 Production function analysis of soil properties and soil conservation investments in tropical agriculture

Biophysical and socio-economic factors jointly contribute to agricultural productivity. Including these factors together is very important. The production function approach has the ability to combine these two factors together in a single equation. In an example, soil is a key asset in agricultural production and soil erosion significantly depreciates the soil capital and reduces crop yields along with increasing societal costs. Ekbom and Sterner (2008) examined the role of soil quality and soil investments along with other inputs on crop yield in Kenya using production function approach. Here the farmer is assumed to produce a given output by a specific choice of traditional economic factors – labour, fertilizers, manure and agricultural land, other variables – soil conservation investments, access to public infrastructure and tree capital, and soil capital – represented by the soil properties; these factors are in turn dependent on others like household characteristics (e.g. number of members of the household), soil investments, crops planted and their mix and extension activities provided to the farmers which affect quality. The responsiveness of output to change in various inputs is captured through elasticities. The study showed that soil quality along with soil quality improvements has a positive and significant role on output (elasticity = 0.20) with nitrogen (elasticity = 0.27) and potassium (elasticity = 0.35) increasing the output significantly while high levels of phosphorous (elasticity = -0.22) are actually detrimental to output, thus drawing attention to the need for adapting fertilizer policies to local biophysical conditions. Investments in soil capital have an important role in agricultural output, and thus measures to arrest soil erosion can help farmers increase food production and reduce food insecurity.

Another application of the production function approach study was used by ELD Initiative and UNEP (2015), where they applied a two stage production function approach. In the first stage, it developed econometric model for estimating soil nutrient depletion as a function of biophysical and socioeconomic drivers. In the second stage, it estimated aggregate cereal crop yield as a function of soil nutrient depletion (as proxy of erosion induced land degradation, which is a predicted result from the first stage equation), fertilizer, land, and labour and controlling for unobserved factor. The study also further applied Cost Benefit Analysis as an evaluation tool.

Limitations

The production function method is data intensive and requires observations over a period of time and across farms to get a clearer understanding of the changes in various inputs on output. As some of the investments can impact output with a time lag, use of observations over time and space can better capture these impacts but lack of such data is often a limiting factor. Environmental variables are not easily measurable – thus limiting the use of such variables to one or two. Often several factors that contribute to the output are not considered as they are not easily measured, resulting in biased estimation.

Dose Response Function

The dose response method is similar to the production function approach and investigates the impact of the changes in environmental quality on the desired output (productivity, health etc.). For example, clear dose-response relations can be established in case of pesticide use and disappearance of the house sparrow, pesticide use and farmer's health, water quality improvements and increase in commercial fisheries catch etc. Here the dependent variable is the outcome (agricultural productivity, health etc.) and the independent variables are the exposure variables (levels of various ecosystem inputs, environmental quality input etc.). The method can be quite data intensive.

One common application of dose-response function analysis is the impact of air quality (ozone, global warming) on agricultural production. Dose-response function approaches require the relationship between input (dose) responsible for damage (response) to be well identified along with other variables that influence the relationship. Once the physical relationship between the dose and response are established, monetary values are derived by multiplying the change in output (or the change in a physical indicator of damage) with the price or value of the output or the object that is damaged. Again, note that the prices here should be efficient prices (i.e. prices generated by free markets in the absence of market power or discrimination or other interventions). The method is very useful in obtaining the marginal values (the impact of addition dose).

The approach can give reasonable approximation of the economic value of the resource. The main limitation of dose-response functions is that they require explicit modelling of the relationship between the input changes and the output, which is possible but data intensive. Additional complications can arise in case of interactions between several inputs. For example, the impact of consuming sugary food on health depends on individual genetic make-up, life style etc. Shea (2003) argues that children are at high risk of developing infections with drug resistant organisms linked directly to the agricultural use of anti-microbials. In such cases it may be too complicated to establish such a direct causal relationship. The dose-response technique can be further complicated if in response to the reduction or loss in ecosystem service, consumers and producers change their behavioural response, thereby impacting the producer and consumer surplus. Dose-response functions, if correctly estimated, are theoretically rigorous and thus very useful. They are best applied when external factors such as prices of inputs and outputs are not changed by the measures (see **Box 7.2** and **Box 7.3** for examples).

Averting Expenditures /Defensive expenditures

Agents (individuals, firms or governments), exposed to a degradation in quality of an environmental factor, incur defensive expenditures or avert costs in order to avoid a poor outcome (e.g. loss in productivity, poor health, deposition of silt, etc.). All the expenses incurred as a result of this averting behaviour - direct expenses for self-protection (e.g. masks for spraying pesticides, pills to prevent malaria) and indirect costs (including the time costs or the leisure foregone) are considered as averting expenditures.

One example of such expenditures is the cost incurred by individuals, firms, and governments to shift from contaminated drinking water (polluted due to agricultural pollution) to safe sources. Users make a decision on which averting actions to take. Choices available in this case can be purchasing bottled water, installing a water filtration system at home, shifting to uncontaminated source (in case where such a choice is available) and boiling water. For example, Harrington *et al.* (1987) assessed the economic losses of water borne disease outbreak in United States. Each of these cases requires households to change their behaviour and incur out-of-pocket expenditures, which would have been otherwise not necessary in case of non-deterioration of environmental quality.

Box 7.2 Sugar – Not so sweet?

Taxes on sugar-sweetened beverages (SSBs) are being levied (in Colorado, USA, for example, as illustrated in **Figure 7.2**) and proposed in several countries and cities, due to the association of SSBs with poor health and obesity. Unhealthy diets and high body mass index are key risk factors that contribute to the burden of disease; implementation of SSB taxes are thought to help address this issue. An SSB is defined as a non-alcoholic drink with added sugar, including carbonated soft drinks and flavoured mineral waters. Fruit juices and drinks, energy drinks, milk-based drinks, and cordials are generally excluded.

Figure 7.2 Poster of Sugar-Sweetened Beverage Tax in Boulder, Colorado, US (Image source:bouldercolorado.gov.)

The Boulder Sugar-Sweetened Beverage Tax is Here

Starting on July 1, 2017, a 2 cents-per-ounce tax will be imposed on the distribution of drinks made with added sugar and other caloric sweeteners. Initiated by residents at the grassroots level, the Sugar Sweetened Beverage Product Distribution Tax was adopted by Boulder voters in November 2016.

Affected drinks include but are not limited to:

Regular Sodas · Sports Drinks · Sweetened Waters
Energy Drinks · Presweetened Coffees and Teas

Where Will the Money Go?

Health Promotion
Physical Activity Programs
Healthy Foods
Wellness and Chronic Disease Prevention Programs that Improve Health Equity
Nutrition and Food Education
Other Health Programs Especially for Residents with Low Income

For more information, please visit
BoulderSugarBevTax.com

In Australia, Veerman et al. (2016) using epidemiological modelling, found that imposition of a 20 per cent ad valorem tax, assumed to apply in addition to the existing Goods and Services Tax (GST), would result in a decrease in demand for SSBs (i.e. the 'dose'), thereby the Bo and thus the average Body Mass Index (BMI). The study modelled the impact of the tax on nine obesity related diseases and found the proposed 20 per cent tax was estimated to lower the incidence of Type II diabetes by approximately 800 cases per year. The estimated benefit for 20–24 year old males is the equivalent of about 7.6 days in full health per year, of which 4.9 days of in life extension and 2.7 days of improved quality of life. For their female peers the model predicts 3.7 health-adjusted days gained, of which 2.2 from increased longevity. This translates to a substantial gain of 112,000 health adjusted life years for men and 56,000 life years for women (using the Disability Adjusted Life Years approach) over the lifetime of the Australian adult population in 2010. The tax would also generate revenue of around AUD 400 million each year, while the costs to the government to implement the tax was estimated at AUD 27.6 million. The overall health care expenditure over the lifetime of the 2010 population aged > = 20 was estimated to be reduced by AUD 609 million (95 per cent Uncertainty interval (UI): 368 million– 870 million) as a result of this intervention. The annual health care savings rise over the first 20 years and then stabilize at around AUD29 million per year. In other words, the costs of legislation and enforcement of the tax would be paid back 14 times over, in the form of reduced health care expenditure.

While using an averting expenditures approach, care should be taken to ensure that only costs incurred specifically to avoid the undesirable outcome are considered. Sometimes the expenditures are incurred off-site. For instance, soil erosion can increase the cost of dredging or reduce the capacity of reservoirs. To avoid this, governments may protect forests in catchment areas, which requires additional expenditures. Similarly this approach can also be used to quantify the benefit of food safety regulations.

This approach can be used in the following situations:

1) if the welfare losses due to changes in the condition of the resource can be established/anticipated and appropriate actions can be taken to mitigate this loss:

2) The relation between the change in ecosystem quality and the averting action chosen to mitigate the impact can be established and the averting good exhibits no 'jointness' in production (i.e. it cannot be an input into two different production functions simultaneously). Another important consideration is to ensure that the expenditures were incurred mainly due to changes in environmental quality, rather than for other reasons. See **Box 7.4** for an illustration of this approach.

Limitations

The method can estimate only those values that individuals can directly perceive or connect with (e.g. soil conservation, water quality, air quality etc.). In some cases, the individuals may incur multiple averting expenditures and this also depends on risk averseness of the individuals and their income. There is a possibility that the actual risk is different from the perceived risk, which depends on individual's perceptions, attitudes, incomes and other socio-economic factors; thus the averting expenditures may be biased on either side. The values so obtained are only a small proportion of the benefits and thus should be used as lower bound.

Residual imputation approaches

Profitability is a central concern in the farming sector and the rate of return on different farm assets, farm land, labour and management are important factors. The residual imputation approach is most commonly used to judge the productivity of a resource that is not easily measured in direct terms (e.g. impact of management practice, good quality land, use of particular farming technology, value of irrigation water, etc.). Using this approach, the total returns to production are divided into shares based on their marginal productivity until the total product is completely exhausted. Using this approach, which can be seen as a simplified version of a production function, the incremental contribution of each input in a production process can be computed. If prices (or estimated shadow prices) can be assigned to all inputs (other than the particular resource whose value is to be estimated), the value of the residual inputs (e.g. water) is the remainder obtained by subtracting the total value of all factors and inputs from the total value of product. This includes, however, any scarcity rents to other fixed factors not included in the assigned valuations (land could be an example) and has to be seen as the value of all residual inputs.

The residual value represents the maximum amount the producer is willing to pay for a resource for which she does actually make a payment (e.g. land, well-drained soil or water) and still cover all other factors or input costs (land, labour, technical inputs etc.). Turner (2004) states the following conditions under which this approach is valid: 1) factors other than the resource considered are rewarded an amount equal to exactly the value of their contribution to net revenue in the contribution they make to production; 2) all other factors of production employ productive inputs to the point at which the marginal product is equal to the opportunity cost; 3) the surplus over and above the cost of production is attributable to the remaining factors in production. As this approach is extremely sensitive to the variations in the nature of production or prices, it is most suitable where the residual input contributes significantly to the output (e.g. well-drained soils, irrigated lands). This approach can be used to compare the per acre returns for different practices. It can also help in the analysis of management practices, e.g. the use of inorganic vs. organic fertilizers etc. A further application would be its use in obtaining the value of input that substantially adds to gross value added but one that is an intermediate good for which well-established markets do not exist (e.g. pollen services in fruit production). The additional returns represent the maximum amount the producer would be willing to pay for use of the resource, after accounting for any other factors that may have been excluded from the list of measured variables in the analysis. In **Box 7.4** an example is provided to illustrate this approach.

Limitations

The method is valid as long as the requirement of the competitive model is satisfied. If the factor inputs are not employed at the level to where their unit prices are equal to the value of the input in terms of what it contributes to production (known as the marginal value product in economics), this method gives erroneous results.

Replacement/Restoration costs/cost savings technique

Replacement cost/restoration cost techniques approximate the benefits of environmental quality by estimating the costs that would be incurred by replacing/restoring ecosystem services using artificial technologies. It can be applied only if replacement is indeed possible and cost-effective. The technique differs from averting cost, which infers value from actual behaviour (revealed preference). In this case, the substitute that replaces the ecosystem asset should provide a service similar to the original ecosystem asset.

Box 7.3 Health costs from exposure to pesticides in Nepal

Use of pesticides has significant negative impact on farmer's health including headaches, dizziness, muscular twitching, skin irritation and respiratory discomfort in addition to ecosystem health. Based on data collected from January to June 2005 from 291 households in Central Nepal, taking into account household demography, personal characteristics, farm size and characteristics, history of pesticide use, history of chronic illness and property of the households, Atreya (2008) estimated the health costs associated with pesticide exposure in rural Central Nepal. The cost of illness and averting action approach was used to estimate the cost of pesticide use.

In the first step, the probability of falling sick was measured by a set of acute symptoms during or within the 48 hours of pesticide application, and the possibility of taking averting action (i.e. costs associated with precautions taken to reduce direct exposure to pesticides, such as masks, long sleeved shirts or pants sprayers, etc.) was modelled on a set of socio-economic, environmental and individual characteristics. The dose response and averting actions are specified as a function of insect and fungicide doses applied (defined as concentration multiplied by spray duration), average weekly temperature, education levels, training in pest management, and farmers' body mass index. Greater exposure is expected to lead to greater averting action.

The cost of illness (COI) and averting actions are used for valuing health damages due to pesticide exposure. The health care costs considered are the costs of consultations, hospitalizations, laboratory tests, medications, transport to and from clinics, time spent travelling, dietary expenses resulting from illness, work efficiency loss, work-days lost, and time spent by family members in assisting or seeking treatments for the victim. The health care costs (annualized with the expected life spans) are predicted for users and non-users of pesticide respectively as the sum of weighted average annual treatment costs (and productivity losses) and average costs of averting actions for users and non-users, with the probabilities of falling sick due to pesticide exposure for users and non-users used as weights respectively. The actual health costs for an individual due to exposure to pesticides is calculated as the difference between the costs for the two groups. The predicted probability of falling sick from pesticide-related symptoms is 133 per cent higher among individuals who apply pesticides compared to individuals in the same household who are not directly exposed. Households bear an annual health cost of NPR 287 ($4) as a result of pesticide exposure (10 per cent of annual household expenditure on health care and services). These costs vary with fungicide exposure. A ten per cent increase in hours of exposure increases costs by about twenty-four per cent. Taking into account the averting costs, the total annual economic cost of pesticide use for the population of Panchakhal and Baluwa Village Development Committees is estimated to be NPR 1,105,782 (US$ 15,797) per year in the study area, which is equivalent to 55 per cent of the annual development and administrative budgets that the two village development committees receive from the Government of Nepal.

Box 7.4 Value of irrigated water in agriculture using residual imputation method

The value of water can be estimated through both observed market behaviour (water rights, value of land etc.) methods, direct techniques which elicit information (demand for water as final good, e.g. water markets) and indirect techniques inferring economic value (where water is an intermediate good). The most commonly used methods to value water as an intermediate good are the production function approach and residual imputation method. Most often in developing countries water is not priced efficiently or is underpriced. In Jordan farmers pay a very negligible price for water and actual market behavior is not relevant. Water is subsidized and farmers view this as free gift. Hence any technique that relies on asking farmers to state their willingness to pay does not yield good estimates.

Using the Residual Imputation method, the value of irrigation water has been estimated by Al-Karabelih et al. (2012) in Jordan. The average value has been estimated to be JD 0.51/m^3 at the country level (approx. USD0.72/m^3), which amounts to a significant share of total value. Other factors include labor, machinery, fertilizer etc. The study revealed a high level of variability in irrigation water values. It was shown that the differences in water values can be mainly attributed to two factors that can be relevant for policy makers and extension services: (1) the characteristics of irrigation system and (2) the type of crop grown. The aggregate average water value for field crops was 0.44 JD/m^3 (0.62 USD/m3) for the vegetable crops in this study it was 1.23 JD/m^3 (1.73 USD) and for fruit trees is 0.23 JD/m^3 (0.32 USD) . The aggregate average water value for horticulture is 0.51 JD/m^3 (0.69 USD/m3).

This technique has been widely used to estimate the value of soil conservation – micronutrients, soil carbon – but also irrigation, pollination services, water retention capacity etc. Deforestation, shifting cultivation and poor agricultural practices can accelerate soil erosion with both on-farm and off-site. The key on-site impact is a decline in productivity due to loss of topsoil and nutrients, organic matter and water retention capacity of the soil. Improper irrigation practices can also reduce the quality of soil due to salinization. In both cases, the replacement cost technique has been commonly used, as it is relatively easy to observe actual expenditures made and engineering estimates are widely available. An important assumption of this method is that the individuals affected by the change in ecosystem service would be willing to incur the costs needed to replace the services provided by the original asset. The approach can provide reliable estimates only if we have reason to believe that the replacement costs incurred are less than aggregate Willingness to Pay (WTP) (Bockstael *et al*. 2000) for the benefits of the original asset that is replaced or restored. In this case, when correctly used, the technique can provide a lower bound of value.

The replacement cost method, although very popular, can be used to estimate only a few ecosystem service values (for which the substitutes or the engineered substitute can provide the same quality and level of service – for e.g. pollination, micronutrients, irrigation, water retention capacity etc.). The cost savings method estimates the value, in terms of savings relative to the use of the next best marketed economic alternative, and this approach has same limitations as that of the replacement cost method.

However, not all inputs can be bought or are substitutable. In this case a closer proxy is used. For example, the only way to substitute for the lost micronutrients from soil erosion is to add more fertilizer. In this case the impact of change in soil quality or environmental capital is estimated by valuing the increased cost of the substitute fertilizer[7]. As this input has a market price, the additional cost of that input represents the value of the lost micronutrients. Caution should also be taken in the use of market prices – these prices must be 'efficient prices' -i.e. they should include any externalities (arising due to market imperfections and policy failures) generated in the production of the fertilizer or associated with damage from runoff. **Box 7.5** provides an example of application of this approach.

Limitations

Replacement cost uses costs as a proxy for benefits, which is not accurate in all situations and thus could provide a lower bound to the true cost only if used accurately. The main assumption here is that the environmental service being replaced is of comparable quality and magnitude and the least costly alternative is chosen among the set of alternatives available to provide a similar level of service. If the substitute chosen is not the least costly alternative, the replacement cost estimates can be overstated and thus misleading. The second assumption is that the cost of replacing or restoring the environmental service does not over- or underestimate the loss in service, which is often not the case (for e.g. in case of soil erosion, some soil may be deposited on-farm and some off-farm and thus may not be completely lost). The method can be applied only when the benefits from the ecosystem services are larger than the cost of producing the services through substitute means. Several resources cannot easily be restored or

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[7] In estimating such an impact, it is important to have an estimate of the productivity of the micronutrients in the production function. If this is not measured the estimate of the amount of fertilizer needed will be biased.

replaced (e.g. climate, water, species extinction). This method can only capture use values but not non-use values. Furthermore, the approach cannot provide marginal values. Despite its limitations, it is widely used owing to the ready availability of market data but a great deal of care is needed while using this technique.

Box 7.5 Valuing Insect Pollination Services with Cost of Replacement

Insect pollination is a key input for approximately 84 per cent of the 300 commercial crops grown worldwide. What options do farmers have if wild insect pollinators do not provide this service? Existing alternatives include pollen dusting, hand pollination and managed beehives (domesticated bees). Using the Western Cape Deciduous fruit industry in South Africa as a case study, due to its dependence on managed honeybees, Allsopp *et al.* (2008) estimated the value of both wild and managed pollination services. Two scenarios were considered: 1) no insects (wild or managed) remain for crop pollination; 2) managed pollination is not commercially viable or possible, leaving only wild pollination services.

Possible options for the replacement of pollination services are limited: 1) the use of managed non-honeybee pollinators, which is not considered feasible in the Western Cape; 2) producing fruit without fertilization, which is not a practical short term solution; 3) pollination by mechanical means, which requires pollen to be collected from appropriate cross-pollinating cultivars, and then applied either by hand or mechanical means (e.g. pollen dusting). Pollen dusting may be done by aircraft and helicopters (efficacy unverified) or with hand operated pollen blowers. Hand pollination entails the manual application of pollen to the stigmas of individual flowers by means of a paintbrush or similar tool. Three hand pollination methods were considered. The output of fruits resulting from pollen dusting is estimated to be 73.5 per cent less as compared to insect pollination. Fruit weight from pollen dusting is estimated to be 42 per cent less when compared to insect pollination. By contrast, hand pollination of flowers is expected to deliver equal or more fruit output than insect pollination and as big or bigger fruit. Depending on which of the four value estimation methods were used, replacement values varied significantly due to differences in pollination efficiencies and the costs of different replacement methods, ranging between 0.23–1.30 of proportional production estimates. However, irrespective of the choice of replacement method, the value of wild pollination services has been underestimated in the past.

Caution: It must be noted that the estimated replacement cost may not reflect actual producer behaviour.

Table 7.3 Pollination service values using different approaches (to the Western Cape deciduous fruit industry), US $ millions, 2005 (Source: Allsopp et al. 2008)

Valuation method	All insect pollinators	Managed pollinators	Wild pollinators	Ratio of wild to managed value
"Traditional"				
Total production value approach	501.0	378.3	122.7	0.32
Proportional (dependence) production value approach	358.5	312.2	46.3	0.15
Revised service value estimates based on experimental evidence				
Proportional (dependence) production value approach	338.3	119.8	218.5	1.82
Production value derived from pollination services	333.9	118.0	215.9	1.83
Cost of pollination (hive rental)				
Current direct cost	-	1.8	-	-
Estimated direct cost assuming managed honeybee substitution	4.3	1.8	2.6	1.44
Pollination service replacement value (income lost)				
Pollen-dusting	292.9	107.8	185.2	1.72
Hand pollination (method 1)	161.2	44.9	116.3	2.59
Hand pollination (method 2)	433.8	122.8	310.9	2.53
Hand pollination (method 3)	77.0	28.0	49.1	1.75

7.3.3 Revealed Preference Approaches

Revealed preference approaches draw statistical inferences from observations based on actual choices made by people in markets. The travel cost method and the hedonic price method, discussed below, fall into this category. For example, individuals value different environmental attributes (for example, clean air, landscape, etc.) and reveal their preference for these attributes through the market price they pay to buy a property. Similarly, individuals reveal the value they hold for a particular ecosystem by their travel choices and the costs they incur to visit that location. By estimating a relationship between the observable choice variable, individual specific variables and the price they pay to obtain it, we can estimate the value of marginal changes in the choice variable (say an environmental attribute) under consideration.

Hedonic Pricing techniques

The hedonic pricing method became popular after Rosen (1974), showed how a homogeneous good (house, land, job, etc.) can be regressed on its characteristics or services and the unique implicit price of each attribute can be estimated if the markets are in equilibrium. The method can be applied to commodities, products or services with clearly differentiated attributes (e.g. organic vs. inorganic products). The method has also been used to establish the relationship between wages and job attributes (for example, exposure to harmful chemicals). Productivity of agricultural land depends on various attributes (agronomic variables, neighbourhood, environmental and policy variables) and the land prices indicate the value that consumers or producers are willing to pay for these attributes. Two different pieces of land may look identical but their characteristics and environmental attributes (e.g. soil quality, biodiversity) may be different, and thus they may fetch different prices.

The price differential between the lands due to difference in one such characteristic can be used as a measure of the marginal value of the characteristic. This is called the "Hedonic Price method". The technique has been widely used to measure various characteristics such as the implicit price for soil (Miranowski and Hammes 1984), the impact of soil erosion (Gardner and Barrows 1985; Ervin and Mill 1985), the value of erosion control (Palmquist and Danielson 1989), impact of climate on agricultural productivity (Mendelsohn *et al*. 1994, Dinar *et al*. 1998, Maddison 2009), the recreational and amenity benefit from agricultural open space or the dis-amenity from intensive animal production to adjoining properties.

Using the hedonic price method requires two steps. In the first step, the value of agricultural land per unit (hectare, acre) is estimated as a function of the quality of land, neighbourhood and environmental characteristics. Once this function is estimated (which is the hedonic price function), the implicit price (change in price/value of land due to change in any of the attributes) for each of the statistically significant attributes can be computed (which could include ecosystem services). This price is the first derivative of the implicit price function with respect to the attribute/service considered. In the second step, the implicit price is regressed on the quantity of the characteristic as well as the socio-economic characteristics of the farmers to estimate the changes in welfare due to changes in the particular environmental or ecosystem service attribute (see **Box 7.6** for illustration).

Key advantages of this approach include: 1) the method allows compressing the attributes of the composite good into one dimension, 2) the approach can be used to reflect the marginal trade-offs between different attributes through examining the difference in prices for change in different attributes (Rosen, 1974).

Limitations

The method can only be deployed to estimate use values. The key assumption of this technique is that information on the land and its attributes is readily available to the farmer, who can then factor this into a decision on how much to pay for the land. Another limitation of this approach is that agricultural markets are rarely as dynamic as housing markets. The data requirements, as is the case with several other methods, can be quite intensive. The method works well if markets can pick up quality differentials, which may not be the case for agricultural land, due to the non-observability of some attributes (e.g. some bio-physical features).

Travel Cost Method

The travel cost method, first used by Hotelling (1947) can estimate the value of recreational sites, which may be public or quasi-public goods8 (e.g. recreational value of agricultural landscapes). The model uses actual expenditures and other costs (including the value of time) incurred by individuals in visiting a specific recreational site to estimate the value of the benefits obtained from the site. Primary data are collected from a sample of tourists visiting the recreational site. The survey includes information on the place of origin of the tourist, the expenditure they incurred, their mode of transport, the time spent on site, along with various socio-economic characteristics. A demand curve is generated with the visitation rate (number of visits per period) as the dependent variable and distance, cost per trip, presence of substitute sites, socio economic

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8 Quasi -public goods have characteristics of both private and public goods and are partially excludable (i.e. the party responsible for managing the good can prevent others from using it), partially rival/congestible (i.e. if one person benefits from the good, others cannot fully benefit from it).

conditions as explanatory variables (Garrod and Willis 1999). From the resulting demand curve, the consumer surplus can be estimated. The underlying assumption is that people will visit a site only if the marginal benefit of recreation is at least as large as the marginal cost (see **Box 7.7** for the illustration).

Limitations

One of the assumptions of the travel cost method is that there is a clear perceived relationship between the environmental attribute in question and visitors' travel patterns, which may not be true. In many cases, visitors know the quality of a site only after they visit; it can therefore be difficult to value changes in recreational or environmental quality. In addition, the method is quite data intensive and can be complicated if the tourist visits multiple sites on a single trip. The method can only be used to obtain use values. The method does not give reliable results if the site or travel zones are very close to each other or if there is not enough variation in the explanatory variables. The method is also very sensitive to the type of statistical analysis chosen and to how the opportunity cost of time is measured.

7.3.4 Stated Preference Methods

Stated preference approaches are based on eliciting values directly from a set of the affected population. There are two broad methods: contingent valuation and choice experiment.

Contingent Valuation Method

The contingent valuation method has been extensively used for the valuation of non-marketed environmental resources (see **Table 7.4**). The approach requires eliciting individual preferences directly through individual surveys (a stated preference approach) through simulating hypothetical markets. The survey aims to understand the preferences of individuals by describing a scenario (i.e. describing the good, provision of the good, existing state of the environment), and how the provision would change under different management responses or hypothetical alternatives. The scenario also mentions who would provide the good and how. Respondents are then asked to state their willingness-to-pay (WTP) to avoid or willingness to accept (WTA) this change using different elicitation methods and the payment vehicle (taxes, user fee, one time payments etc.). It should be noted that the WTP and WTA may be different. Along with this, some information on the socio-economic background of the individuals, their knowledge on environmental issues, their attitudes towards environmental good under consideration as well as the preferences for general environment is also elicited. The demand for the environmental good is then estimated through different econometric approaches.

Box 7.6 The value of natural landscapes: application of the Hedonic Price Method

Living in close proximity to nature provides positive welfare benefits through improved health and well-being. These cultural services provided by agricultural landscapes can be estimated through stated and revealed preference techniques. Hedonic price studies have been commonly used to investigate the effect of environmental amenities on property prices (for instance the impact of water quality, or proximity to protected areas such as wetlands, forests, beaches, scenic views, or open spaces on property prices).

Walls *et al.* (2015), using property sales data from the St, Louis Country, Missouri, Revenue department for the years 1998 through 2011, estimated the value of home's sale price as a function of the percentage of its view that encompasses various 'green' land covers – forests, farm land and grassy recreational lands, as well as proximity to such green spaces. Data was also collected on structural characteristics of relevant buildings, such as number of stories, square footage, number of bedrooms, and lot size among other attributes. The hedonic price function has been mapped with georeferenced parcel boundaries. The property price (adjusted for inflation) has been estimated as a function of building age, the share of property in natural land cover, the diversity of the view of the property, and the year of sale, using a fixed effect panel data model. The results from the model suggest that proximity to all three kinds of open space has positive value to home buyers, but the effects of views are more mixed. The larger the forest view from a property the lower the property price (because people valued a more mixed landscape rather than a single monotonous view in this particular case), all else being equal. However, the farmland and grassy land have positive effects, with farmland coefficient being statistically significant. A 10 per cent increase in the amount of farmland in a home's 'view shed' leads to an increase in almost 2 per cent of its price. The reason for significant positive value of farmland on home sale prices is due to the scarcity of the farmland due to their increased conversion for property development.

Limitations

Contingent valuation has been widely used in the environmental valuation literature and in several circumstances remains the only method available to estimate the non-use values. However, the method is complex, data intensive, costly to implement and requires carefully designed surveys to gather unbiased information. The estimates are dependent on the respondent's knowledge, ability to understand and visualize the circumstance of the good or service being considered. Respondents may understate or overstate their WTP/WTA depending on their beliefs and other factors not related to valuation.

Choice Experiments

In choice experiments, rather than presenting a single scenario respondents face a sequence of choice sets. These present different environmental attributes of varying quantity and quality including the cost to provision the good or the price the consumer or user may have to pay to obtain the good. The respondents' preferred option, in response to the change in attribute levels, are modelled to determine the people's WTP or WTA for the changes in different levels or quality of attribute under consideration. Thus it is possible to see how people trade one attribute or preference against the other and the welfare changes can be calculated (see Box 7.9 for application of choice experiment technique).

Limitations

The choice experiment method is based on the notion that attributes of the good being considered can be used to understand the trade-offs. However, the success of the method depends on selection of the appropriate attributes and levels. Unfamiliar trade-offs, too few alternatives or too many alternatives may give incorrect estimates as the respondents or may end up choosing the alternatives that are simpler.

Box 7.7 Value of Ranch Open Space in Arizona

Agriculture provides positive externalities, but the land market may not be working efficiently to capture the value of such externalities. Rosenberger and Loomis (1999) measured the benefits to tourists associated with ranch open space in the resort town of Steamboat Springs in Routt County, Colorado. The traditional ranch practices in Yampa River valley have preserved open space, with more than 10,000 acres of privately owned ranch land in the area. However, the area near Steamboat Springs lost approximately 20 per cent of its ranch land to development uses between 1990 and 1995. Thus research seeks to answer the question, "Do people choose to visit the area, in part, because of the existing ranch landscape, and how much does it contribute to the enjoyment of a Steamboat Springs summer visit?' And "How would visitation rates change with additional subdivision of valley ranch land?"

Survey data was collected through in-person interviews of 403 adult visitors on stratified random days. Information on the characteristics of summer visitors to the resort area, including state of residence, mode of travel, type of lodging, choice of recreation activities, spending patterns and attitudes towards services provided in the area were collected. The observed behaviour data collected included total number of trips and total number of days the individual expected to spend in the Steamboat Springs area during the summer season and the distance between their home and another resort area with comparable ranch open space. The contingent behaviour questions asked whether they would increase, decrease or not change their current visitation rates if all the current ranch open space were converted to urban and tourism development uses. If they stated they would change their rate of visitation, they were asked to state the number of days. The change in the number of days was computed by first estimating the average number of days per trip spent onsite based on observed levels and then adjusting the number of trips spent onsite based on observed levels, and then adjusting the current number of trips by the ratio of days per trip based on the contingent number of days. The model was estimated using panel data Poisson technique. The average consumer surplus (a measure of welfare) per group trip is estimated by estimating the area under the estimated travel cost demand function (or integrating under the demand curve), which plots the number of trips on the horizontal axis and the cost per trip on the vertical axis. The integration is carried out between the average travel cost per trip and the maximum price at which no trips are made. This is done both under the current conditions and hypothetical condition without ranch space. The average consumer surplus received per group trip was $1,132 with existing ranch open space. This value was used to value the changes in number of visits when open space was altered and thus to compare benefits from visitors with benefits from ranching.

Box 7.8 Consumers attitudes towards to Genetically Modified Organisms in the UK- Application of choice modelling

Gene technologies, while significantly benefitting society, can pose potential risks to humans. While the benefits, such as higher productivity, are immediately realized, the risks of affecting other plants and species are often not immediately visible, and thus countries have regulations enforced to protect the health and safely of people and to safeguard the environment. For example, the EU has placed restrictions on the import of genetically modified soya, and the UK food and drink manufacturer and retailers agreed to label foodstuffs containing GM soya or maize protein.

Burton et al. (2001) set out to identify consumer WTP to avoid these products in order to help in identifying the appropriate level of policy response. Choice modelling approaches require presenting different attributes to users or consumers, and in this case of GM crops, the consumer was presented two attributes in each option in the form of technology used to produce food (traditional or GM) and the level of the weekly food bill for the individual. In selecting between these two, the respondent was asked to compare the reduced food bill with the change in technology. Option 1 is chosen if the welfare from its level of attributes is preferred to that generated by Option 2. Three production technology levels were identified: traditional, plants modified by plant genes and plants modified by both plant and animal genes.

The survey was administered over the summer of 2000 in Manchester UK using drop-off and collect approach. A total of 228 complete surveys were obtained over a six-week period, seeking to answer how much consumers would be willing to pay to avoid GM technology, computed as change in food bill. The inclusion of food bills acts as payment vehicle. Personal characteristics were included in the analysis, interacting with attribute levels to explain the choices. The study found a univocal aversion to GM food across all users – infrequent, occasional and organic food users. The infrequent group was prepared to pay 13 per cent more on food bills to achieve a 10 per cent reduction in GM use.

7.3.5 Risk, Uncertainty and Quasi-Option Values

The discussion so far has been on methods for eliciting certain values of eco-agri-food systems that are normally unaccounted for in decision-making processes. In this subsection we consider certain categories of value that are important in decision making for this sector. They may be elicited through a variety of techniques; what is critical to understand where they come into play in the decision-making process.

The agriculture and food industry is subject to significant risks and uncertainty, which adds a considerable degree of complexity to decision making. Imperfect knowledge about the future is referred to as risk, if the likelihood of consequences is known and probabilities used. If the likelihood is not known, the lack of knowledge is referred to as uncertainty. Broadly speaking the risks in agriculture arise from the variability in market prices, exchange rate fluctuations, government policies; uncertainty arises due to the natural variability in the production of crops, weather, incidence of pests and diseases (e.g. foot and mouth disease, incidence of E.Coli), food quality and safety, catastrophes and climate change.

Despite risk and uncertainty, decisions have to be made regarding the allocation of resources. The nature of the decision depends on whether the individuals or businesses are risk averse, risk neutral or risk loving. Risk averse farmers, for example, adopt diversified farming systems, buy crop insurance (drought or flood insurance) or undertake actions to adapt to risk and uncertainty (such as supplemental irrigation measures to offset the risk of insufficient rainfall or constructing dams and levees to control flooding). Accessibility of information plays a crucial role in decision-making, especially considering the irreversibility of certain decisions, and thus it is important to value the information. For example, biotechnology increases crop yields, reduces pesticide costs and enhances crop adaptation. However, there are potential risks to human and animal health and irreversible risks to the environment. While the benefits are known with some certainty the costs (the risks) are uncertain. As a result, some countries have adopted a precautionary approach, an example of value of information by delaying the action, which is the quasi-option value.

The quasi option value is the value gained by waiting for additional information before making an irreversible investment (Arrow and Fisher 1974). **Box 7.9** illustrates the example of quasi-option value from delayed input use from Magnan *et al.* (2011). Drought is a major risk factor where farmers can have three alternatives to choose from – farming in locations known to have lower risks, investing in irrigation structures, or choosing crops, technologies or seeds that are drought resistant and/or adjusting input use in growing seasons (Magnan *et al.* 2011). Farmers who are flexible in adjusting their input use can choose between no till (NT) agriculture and conventional tilling (CT). However, the inflexible farmers do not factor the stochastic rainfall in their decisions in period 1 and thus cannot change the decisions later on. The difference in the profits between CT and NT gives the quasi-option value.

Box 7.9 Quasi option value from delayed input use

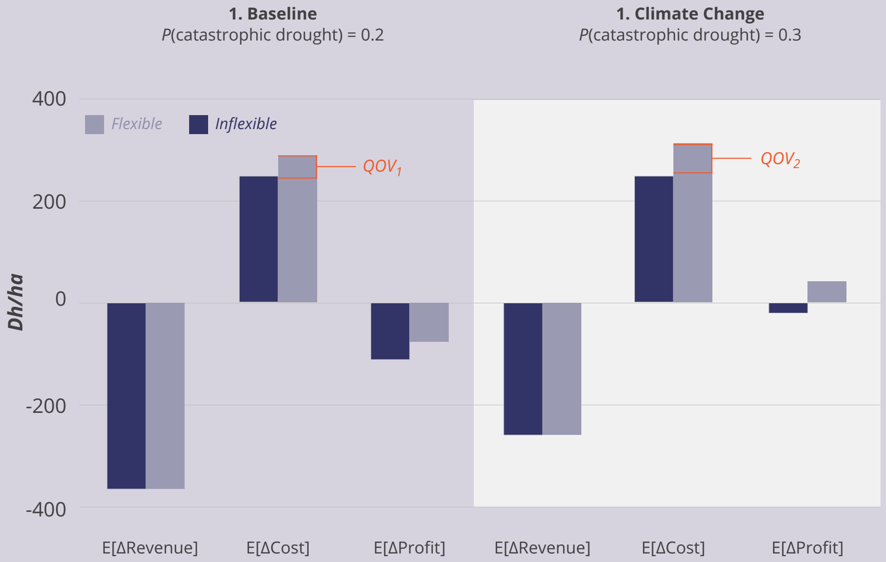
No-till agriculture (NT) allows farmers to forgo plowing by seeding directly through the stubble of previous years' crops, which the farmer is required to leave on the field. The benefits of no till agriculture are: lower planting costs (leaving more resources to replant), improvement in soil quality, efficiency in water use, higher yields in years of mild drought and many environmental benefits in the form of lowered emissions, reduced erosion and increase soil organic carbon. In addition, NT changes the input timing so that relatively fewer costs are incurred early in the growing season (lower pre-planting costs but higher costs during the growing season) compared with CT. However, the risk is that cost savings may be offset by the increased crop protection costs and higher fertilizer use at a later stage to maintain the same yield. The flexible farmers (willing to adopt NT) may get lower yields than the conventional farmers due to greater experience with CT. Farmers may perceive additional risk with NT than CT. The decision to opt for till or no-till has to be taken at the beginning of the planting season when he does not have information whether there would be normal rainfall or drought. Based on surveying 197 rainfed wheat farmers in Morocco, Magnan et al (2011) estimate the quasi-option value. Two scenarios are assumed – base case (catastrophic droughts occur with 0.2 probability) and climate change (which increases the probability catastrophic droughts to 0.3). The decision-making matrix of the farmers is based on the following payoff matrix:

Table 7.4 Expected benefits and costs of decision making under two management scenarios

Time	Action	Base case (probability of catastrophic disaster = 0.2)		Climate change (probability of disaster = 0.3)	
		Costs	Expected benefits	Costs	Expected benefits
t = 1	No Tillage (NT)	1380 Dh/ha	EB(CT) - 356	1380 Dh/ha	EB (CT) - 262
t = 2		1785 Dh/ha		1785 Dh/ha	
t = 1	Conventional Tillage(CT)	1830 Dh/ha	EB(NT) + 356	1380 Dh/ha	EB(NT) + 262
t = 2		1585 Dh/ha		1785 Dh/ha	

Under the baseline scenario, the expected net revenue from No Till (NT) is 356 Moroccan Dirhams/ha ($45/ha) lower than under CT. The inflexible farmer (adopting CT) saves 250 Dh/ha on production costs. Under climate change the expected net revenues of the farmer under NT is assumed to be 262 Dh/ha less than under CT. The cost savings are still the same 250 Dh/ha under this scenario as well. The inflexible farmer in the case of base case scenario saves 250 Dh/ha on production costs. But the flexible farmer receives 40 Dh/ha more of quasi option value. However, in the case of climate change, the quasi option value of delayed input use is 60 Dh/ha, which increases total expected savings to 310 Dh/ha (24 per cent increase) and the total expected benefit of adoption increases to 48 Dh/ha for the flexible farmer (see **Figure 7.3**).

Figure 7.3 Changes in expected revenues, costs and profits from adapting no-tillage (Source: Magnan et al. 2011)



7.3.6 Using Valuation to Derive Aggregate Estimates of External Costs and Dependencies

The previous section reviewed the methods available to value farmers' dependencies on ecosystem services and the externalities related to eco-agri-food systems (positive and negative). **Table 7.5** summarizes the findings from that review. Each method has strengths and weaknesses. Despite the limitations, if used with care these valuation methods can generate reliable estimates of the external costs of different combinations of agricultural practices.

One limitation that merits special mention is that these valuation methods do not directly deal with the question of *who* gains and who loses from a change in ecosystem services. The focus is on aggregate gains and losses and, while these are made up of gains and losses to individuals or particular groups, the breakdown is not generally presented in the reporting of results. Such distributional aspects are of course important, as they bear on the social capital of a community or society. They emerge as issues to be considered in any wider evaluation of the changes under consideration. It is important to note, however, that data relevant to such an evaluation can often be found in the detailed assessment of the values of ecosystem services (ESS).

Table 7.5 Methods for Valuation of Ecosystem Services (Source: authors)

Method	Data Required	Best Suited For	Main Limitations
Market Values	Prices and quantities of the inputs and outputs	All cases where market data are available	Cannot be used to value those services that have no market value
Production Function	Quantities of inputs and outputs in physical units. Prices of key outputs and inputs	Cases where data on a wide set of inputs and outputs is available	Gives biased estimates when data is missing on key inputs and when prices change.
Dose Response functions	Input in question and outputs that are affected	Cases with clear links – e.g. air pollution, weather/ climate	By itself does not take account of more complex responses to changes in dose on production across sectors.
Averting expenditures	Expenditure to avoid a negative externality and magnitude of the externality	Cases where strong averting behaviour is observed	Complex responses that may include an element of averting behaviour are difficult to model and need a lot more data
Residual Imputation Approaches	Data on all inputs and other outputs except the one of interest.	Estimation of the residual value of one ESS	It is rare to get all other data so values for the residual will contain more than just the value of the input of interest.
Replacement/ Restoration	Data on amount of ESS los and cost of replacement	Where one ESS is reduced and it is reasonable to assume you will want to find a replacement	Not based on willingness to pay. Costs are used as a proxy for benefits, which is not always the case
Hedonic Prices	Price and quantity of the good or service and quantities of all related attributes	Cases where values of land are strongly affected by some ESS	Extensive data requirements and assumption of efficient markets
Travel Cost	Data on number of visitors, cost of travel, attributes of visitors and attributes of sites.	Largely cultural sites and other recreational uses of land	Extensive data requirements. Estimation of opportunity cost of time
Contingent valuation/ Choice experiment	Survey data on money values of individuals given hypothetical information about a situation	Cases where individuals are able to express clear preferences Non-use values	Biases in answers possible but can be limited be design. Data requirements are extensive

In **Box 7.10** that follows, some examples of the application of valuation methods to estimate aggregate (national or regional) external costs are presented. While there are many gaps that need to be addressed, the applications described in Box 11 show the power of valuation methods for estimating the effects of externalities related to agriculture on the sector and on society at large. The studies summarized here have been included to give an idea of the total value of external costs that emerge from the literature and what they tell us about where the externalities arise.

The research by Pretty *et al.* (2005) showed an external cost for the UK in 2005 of around 0.1 per cent of GDP, which may seem a small figure but includes potentially significant costs for human health and emissions to the atmosphere. Interestingly, the costs were estimated to be considerably lower (75 per cent less) if all production were to go organic. Other studies also show that significant reductions in external costs can be achieved at the national or regional scale if measures for conservation are introduced. These studies are not without criticism, but they are important in showing what could be done using the methods described here. Further improvements in estimates can be expected once approaches described in this report are put in practice.

Box 7.10 Application of externality valuation to estimate the aggregate impacts of agricultural practices

A value-based approach was taken by Pretty *et al.* (2005) who undertook an economic analysis of the costs imposed by the UK food system. The external costs of the current agricultural system were compared with those that would arise were the whole of the UK to be farmed with organic production systems (see **Table 7.6**). They used standard organic protocols to estimate the contribution that would be made to the total costs by each of the ten sectors listed in the table. The study assessed the full cost of the UK weekly food basket by estimating the environmental costs to the farm gate for 12 food commodities, and the additional environmental costs of transporting food to retail outlets, and then to consumers' homes, and the cost of waste disposal (shown in **Table 7.6***)*. The methods used in these studies were largely cost-based rather than demand-based, and involved the use of replacement costs (e.g. hedgerows, wetlands), substitute goods (e.g. bottled water), loss of earnings (e.g. due to ill health), and clean-up costs (e.g. removal of pesticides and nitrate from drinking water). The results show a considerable reduction in costs from a switch to organic production. The present costs are also measured relative to the amount paid and found to be about 12 per cent of that figure. No attempt was made to assess the savings in external cost relative to the higher cost of shifting to organic production. The valuation methods have improved considerably since this study was done, but it is still one of the few studies that values the external costs in a way that covers the full value chain as set out in **Figure 7.4.**

Other studies that measure the loss of ESS related to agriculture include Pimentel *et al.* (1995) and Gascoigne et al. (2011). Pimentel *et al.* (1995) estimated damages caused by soil erosion in the US and compared them against the costs of avoiding erosion. Erosion was valued in terms of additional energy, nutrients and water needed to maintain a given level of production, as well as the costs of siltation and damage caused by soil particles entering streams and rivers and harming habitats. Total damages amounted to about USD 100 ha^{-1} $yr^{-1.}$ Costs of conservation through methods such as ridge planting, no-till cultivation, contour planting, cover crops and windbreaks were estimated at around USD 45 ha^{-1} yr^{-1}, thus providing a healthy net benefit in overall terms. Valuation methods did not, however, include the recent work on damages from pesticides and fertilizers on streams and rivers.

Gascoigne *et al.* (2011) compared the societal values of agricultural products and ecosystem services produced under policy-relevant land-use change scenarios and explored the effectiveness of mitigating loss with conservation programs in the native prairie pothole regions of Dakota. Crops were valued using market data. ESS of carbon sequestration, sedimentation and waterfowl production were estimated by biophysical models and valued by benefit transfer. The authors evaluated four scenarios for a 20-year period ranging from aggressive conservation to extensive conversion for agriculture, in terms of changes in market and non-market ESS and including any costs incurred in implementing these scenarios. In benefit cost terms, the scenarios where native prairie loss was minimized and Conservation Reserve and Wetland Reserve lands were increased provided the most societal benefit. This included taking account of the value of land lost to production.

Table 7.6 The negative externalities of UK agriculture, 2000 (Source: adapted from Pretty *et al.* 2005)

Sources of adverse effects	Actual costs from current agriculture (£ M yr^{-1})	Scenario: costs as if whole of UK was organic (£ M yr^{-1})
Pesticides in water	143.2	0
Nitrate, phosphate, soil and Cryptosporidium in water	112.1	53.7
Eutrophication of surface water	79.1	19.8
Monitoring of water systems and advice	13.1	13.1
Methane, nitrous oxide, ammonia emissions to atmosphere	421.1	172.7
Direct and indirect carbon dioxide emissions to atmosphere	102.7	32.0
Off-site soils erosion and organic matter losses from soils	59.0	24.0
Losses of biodiversity and landscape values	150.3	19.3
Adverse effects to human health from pesticides	1.2	0
Adverse effects to human health from micro-organisms and BSE	432.6	50.4
Totals	£1,514.4	£384.9

7.4 OVERVIEW OF EVALUATION METHODOLOGIES

The previous section focused on the use of specific valuation techniques that generate monetary estimates of the external costs and benefits of eco-agri-food systems and their dependencies on ecosystems. These estimates are of great value to both public policy makers and private investors, but questions of equity, education and awareness in promoting health practices and contributing more widely to the Sustainable Development Goals (SDGs) should also be considered in food production. In addition, links across the economy, between the eco-agri-food system and other sectors, as well as the contribution of the sector to employment and economic growth will always be important considerations. Evaluation methodologies that help us understand how eco-agri-food systems function in light of these wider goals include:

1. Cost Benefit Analysis `
2. Life cycle assessment
3. Evaluating the role of merit goods
4. Integrated approaches that evaluate several goals
5. Multi-Criteria Analysis and Cost-effectiveness Analysis

Not all the evaluation methods listed above use monetary valuation, although many do. Some non-monetary methods such as life cycle analysis provide data that can be used for monetary approaches, as well as being of direct use in their own right. Other methods, such as multi-criteria analysis, incorporate and extend some of the methods described above.

This section and the next show how these methods can help us better understand and evaluate the performance of eco-agri-food systems across the economic, environmental and social dimensions of the value chain. This analysis could help address issues such as:

- How the development of organic food products affects the incomes of farmers, as well as the sustainability of farming systems

- How the development of 'fair' trade schemes affects the incomes of growers, land use and biodiversity

- How changes in technology that reduce production costs and increase yields affect incomes and consumption habits but may increase external costs

- Increased demand for biofuels and its effects on deforestation, food prices, income of farmers and farming practices

- Effects of trade liberalization on farm incomes across different farm sizes as well as on deforestation and biodiversity

7.4.1 Cost Benefit analysis

Cost benefit analysis (CBA) is a systematic process for calculating and comparing benefits and costs of a given policy or project, based on assigning a monetary value to all the activities associated with the project (either as input or output). CBA techniques are commonly used to evaluate the feasibility and profitability of business strategies and private and public projects, as well as public policy interventions. This approach generally compares the total investment and other costs required for the implementation of the project (which might include investment in fixed assets, labour and training costs, as well as the time utilized for training or implementation) against its potential returns (e.g. increased revenues).

CBA helps make clear the total costs of an intervention, as well as the benefits generated. Additional indicators include the payback period (the time needed for the investment to pay for itself); net present value (NPV, a comparison of the discounted present value of all costs and benefits); rate of return (the percentage return on investment, equal to the discount rate that makes the NPV equal to zero); and benefit to cost ratio, which is the ratio of the present value of benefits to costs (a ratio greater than one would be necessary but not sufficient for a project to be selected). A key feature of CBA is the aggregation of costs and benefits in different periods to a single value using a discount rate. To get one number for the costs of a project and one for the benefits, the analysts add together the costs and benefits in different periods but give lower weight to costs and benefits further into the future. These weights are based on a discount rate. Box 12 below describes the role of the discount rate in valuations, especially CBA.

An early example of the application of CBA methods to eco-agri-food systems was a study by Pimentel et al. (1995), referred to in Box 7.10, where the costs of preventing soil erosion in the USA were compared to the benefits from reducing soil erosion. The study has been criticized as a simplistic scenario but it remains useful as a guide to the method. A more recent example, also referred to in **Box 7.10**, is Gascoigne et al. (2011), which compares the societal values of agricultural products and ecosystem services produced under policy-relevant land-use change scenarios and explores the effectiveness of mitigating environmental losses with conservation programs.

Cost benefit analysis a powerful tool but one with limitations. Most importantly it does not address the distributional question of who gains and who loses. It also gives no importance to non-valued costs and benefits. For both these reasons it is a major input to any evaluation process but is never sufficient to determine the outcome of the evaluation.

7.4.2 Life Cycle Assessment

Life Cycle Assessment (LCA) is defined as: "a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle" (IOS 2016). LCA examines physical impacts across the value chain; it can also be viewed as "a tool for the assessment of environmental loadings of entire life cycle processes related to a production system, covering all the processes, activities and resources used" (Mogensen et al. 2012). For each of these steps an inventory is made of the use of material and energy and the emissions to the environment, creating an environmental profile that allows identification of the weak points in the lifecycle of the system studied. These weak points are then made into the focus for improving the system from an environmental point of view. In most cases the impacts are only reported in physical units and not converted into money terms. An example of LCA applied to food products is Shonfield and Dumelin (2005), who examine the LCA for different kinds of margarine, as laid out in **Figure 7.4.**

Emissions for different kinds of margarine are measured in terms of energy use, acidification, eutrophication, global warming and photochemical smog. In principle it is possible to value these impacts, although such measurements will be subject to considerable error bounds. It should also be noted that not all categories of impacts are negative externalities in the sense that they are damaging to the environment -–for example energy use may not be, if derived from renewable sources. Nevertheless, the LCA can be useful for policy makers and those looking for stages in the lifecycle with significant environmental impacts.

One area that LCA needs to take into account is the indirect land use implications of a policy in the eco-agri-food sphere. Biofuel policies in Europe, for example, are well known to have impacts on land use in developing countries that convert forests to grow palm oil (AETS 2013). However, the problem is more widespread and policies for land set-aside in Europe or other developed regions can also have implications for land conversion in the developing world (i.e. setting-aside reduces production and raises prices, which can impact prices and production in developing countries). For this reason it is important to distinguish between LCA accounting methods that stop at national boundaries and those that include international dimensions in a more global accounting context. The more extensive the coverage the more complete the assessment will be.

LCA is a useful complement to other data sources and can feed into other evaluation tools. It can also provide direct input into tools such as CBA or MCA. The main limitations are difficulties in tracking spillovers from one sector to another and the fact that values are rarely attached to biophysical flows (although in many cases they can be added).

Box 7.11 Discount Rates and Discounting

The discount rate is a parameter used to compare economic effects that occur at different points in time. Societies and individuals prefer, for different reasons, to have something now rather than to have the same thing in the future. Hence future benefits and future costs have a lower value associated with them than present day benefits and costs. If a benefit or cost has a value of $1 in the present period and the same benefit is given a value of $0.95 in one year's time then the discount rate is said to be approximately 5 per cent.

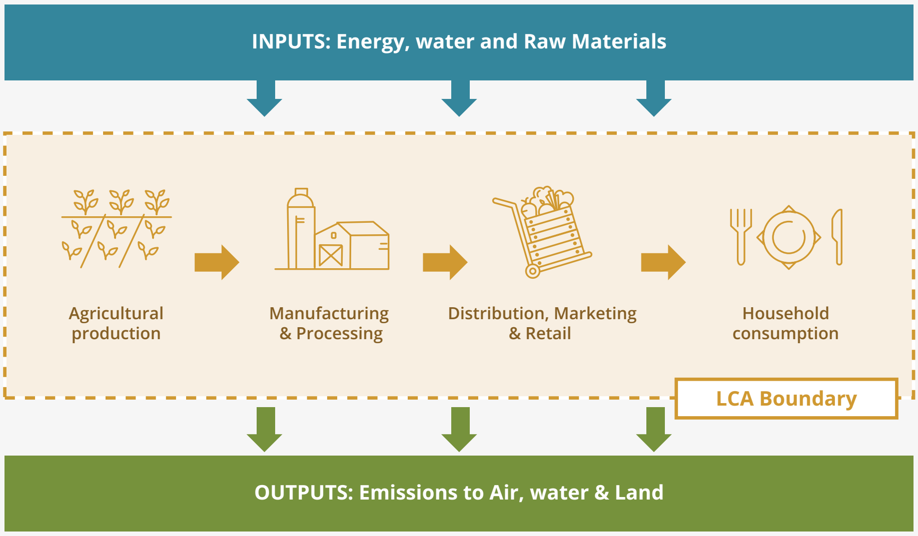
The major question is what discount rate to use when carrying out a CBA. A high discount rate makes it difficult for projects with high upfront costs (but benefits that come in small amounts over a long period of time) to have a benefit-to-cost ratio greater than one. This can make it hard to justify investments in, for example, reforestation or adaptation to climate change. A low discount rate, on the other hand can result in many projects passing the benefit-to-cost ratio test and can often imply large infrastructure projects such as dams being approved, which can also have negative environmental consequences.

Discount rates also matter when valuing natural capital. A World Bank (2006) study valued natural capital in terms of the discounted present value of the services provided by different biomes. One of these is grasslands, often used for agricultural production, where values were based on the current rental rate (i.e. the percentage of the price that is net income) combined with current prices. In the future, both of these were expected to be constant and discounted at 4 per cent. The areas of grassland depended on expected conversion to other uses and rates of degradation. Sensitivity to various parameters was examined. While the choice of discount rates mattered it did so less than assumptions about future prices.

The choice of discount rate varies according to whether it is based on private considerations or social ones. Private sector decisions that involve benefits and costs over time are usually decided on a relatively high rate – 10per cent and more, depending on the risks associated with the project. The public sector rate, however, is lower and can be in the range of 3-5 per cent in most cases. Recently, a case has also been made for adopting different rates in the public sector, according to the length of time for project or program under consideration. In this case benefits and costs are discounted at a higher rate for the earlier years and at lower rates for later years. The governments of the UK and France have adopted declining rates for public sector projects. In the UK for example, costs and benefits for the first 30 years are discounted at 3.5per cent, those for years 31-75 at 3 per cent, years 76-125 at 2.5p er cent, years 126-200 at 2per cent and so on.

How does one reconcile these two different rates? Governments apply the social rate for investments and capital valuations in the public sector and leave the private sector to apply whatever rate it considers appropriate for its decisions. This is a workable solution in most circumstances, except that some private decisions involve investments in and valuations of natural capital, which entail some use of natural capital that is not private. An example would be private investment that may degrade an ecosystem, with loss of services over many years leading to unsustainable outcomes. Creating regulations requiring such assets to be protected during any development by the private sector, based on values using low discount rates, is clearly a possibility.

Figure 7.4 Life Cycle Assessment (LCA) boundaries (Source: adapted from Shonfield and Dumelin 2005)



7.4.3 Analysis Involving Merit Goods

Examining the effect of certain dietary choices on GHG emissions and on the health of the consuming population provides an opportunity to analyse the concept of merit goods. A study by Markandya et al. (2016) looks at what it would cost in terms of loss of ex ante personal welfare for the adult diet in Spain to be modified in order to meet the World Health Organization (WHO) dietary guidelines in terms of calories, fats, sugars etc. The changes in diet are brought about through a model that evaluates a 'bonus-malus' program in which foods that take the diet closer to the guidelines are subsidized while those that take it away from the guideline value are taxed. At the same time the diets are evaluated in terms of their life cycle GHG emissions. The modelling, which consists of looking at demand systems, shows that taxes and subsidies required to achieve the full transition to a healthy diet are too high to be politically acceptable (based on the authors judgment). On the other hand, with taxes and subsidies limited to between 30 and 40 per cent of the current price, an improvement in the region of 20-25 per cent in the diet is feasible (measured in terms of the reduction between the desired diet and the actual diet), while also making a reduction in GHGs that is significant. The dietary changes that the bonus-malus program brings about are a reduction in the consumption of red meat and other high GHG foods and an increase in the consumption of vegetables and low fat foods.

Measures to reduce red meat consumption through awareness programs can be evaluated in terms of the reduction in GHGs (depending on whether other goods were substituting for the lowered meat consumption), as well as expected improvements in health indicators. Both of these can, in principle, be valued in money terms but the methods of analysis generally require looking at more than just the monetary impacts and draws on wider economic analysis than is normal for most externality studies.

Such modelling is valuable in understanding the complexities involved in introducing a policy with a goal that appears to be clear and simple but in reality is not. The difficulty in using it is the problem of obtaining the model parameters and the baseline data.

7.4.4 Integrated Approaches that Evaluate Several Goals

The above review of different analysis of economic, environmental and social impacts of eco-agro-food policies shows a focus on individual impacts, as well as in combinations, notably environmental/economic and economic/social. Rarely, however, has the whole value chain been analysed as an entity. Setboonsarng and Markandya (2015) have attempted to so by addressing a policy of the adoption of organic farming by poor farmers in Thailand, Laos, Cambodia, and Sri Lanka. The methodology used, referred to as the Propensity Score Matching Method, consisted of comparing farmers who had adopted organic farming with another group that was as similar as possible but that had not adopted organic farming. Data was collected on indicators like farm inputs, outputs, income, health status, and education of children. for both groups and the results compared. **Box 7.12** summarizes the findings of a quantitative analysis that looked at the economic, health, gender and environmental impacts of a given policy.

Box 7.12 Evaluating the Impacts of Organic Agriculture in South East Asia

In a quantitative evaluation of the pathways and magnitude of impacts of organic agriculture on the MDGs, Setboonsarng and Markandya (2015) study analyzed 11 datasets from smallholder organic farmers in marginal areas in six countries: Thailand (rice), China (tea), Sri Lanka (tea), Cambodia (Nieng Malis rice), Laos (Japanese rice), and Bhutan (lemongrass). In all but one case, household surveys were conducted on organic and conventional farmers of the same socioeconomic group and agro-ecosystem. The main findings were as follows:

1. Organic farmers earned higher profits than conventional farmers on account of lower production costs and price premiums. As organic agriculture required lower cash inputs, there was less need for credit. Organic agriculture was also pro-smallholder, as small plot size with utilization of family labour often produces better yields. As organic agriculture was more labor-intensive, it absorbed surplus rural labour. This showed especially in the practice of tea growing in China, where use of family labour was as much as 35 per cent higher in organic than in conventional agriculture.
2. In terms of MDG 4 (reduce child mortality), 5 (improve maternal health), and 6 (combat HIV/AIDS, malaria and other diseases), organic agriculture positively affected the health of farmers by reducing exposure to toxic agrochemicals as reflected in their lower medical spending.

With respect to MDG 7 (ensure environmental sustainability), organic agriculture utilized resources with less harm to the environment. The benefits of organic agriculture ranged from increasing biodiversity of farming systems to reducing GHGs in the atmosphere. As revealed in the case studies, organic farmers observed increases in the number and kinds of animal and plant species in their fields. This natural environment, which is not so negatively affected by organic practices, showed how organically farmed land can act as a gene bank that contributes to long-term food security.

7.4.4.1 Value Chain Analysis

One multi-dimensional approach currently being developed to help better determine linkages across the eco-agri-food value chain is ‘value chain analysis’. The approach seeks to represent the linkages across social, economic and environmental indicators for each stage of the value chain in terms of the stocks and flows of produced, social, human and natural capital. The intention is to assess the strength and dominance of feedback loops over time, for indicators of performance that are key to many types of economic actors, as well as for society. The steps involved in applying such an analysis are suggested in **Box 7.13** below.

7.4.5 Cost-Effectiveness Analysis

Cost-effectiveness analysis (CEA) compares the relative costs and outcomes (non-monetary effects) of two or more courses of action. It is narrower than a CBA and excludes any valuation of benefits, focusing instead on the costs of attaining a given target. An example of a CEA would be looking at the cost of different options to restore a given amount of degraded land. Once the area of land and other desired outcomes are defined, the CEA method can help identify the least costly option for achieving that goal. An example is the restoration of coastal areas in Louisiana (Caffey, 2014), where dredge-based “marsh creation” (involving essentially the establishment of a wetland) and diversion-based coastal restoration (where built capital was used to restore and protect coastal areas) projects were compared. A cost effectiveness analysis showed that the marsh creation approach provided similar benefits at lower cost.

The ultimate aim is to assess all three areas of impact (social, economic and environmental), where feedback loops across value chain stages are identified and assessed to capture the vulnerability and risks of the eco-agri-food value chain, as well as risks for society. The TEEBAgriFood Evaluation Framework is laid out as the direction for future work. The intention is that, based on this report and future pilot studies, case studies can be developed.

The tool is widely used in many sectors, including agriculture. It has the advantage of not needing explicit benefit estimates, but the corresponding limitation that it is based on the assumption of a given physical goal as desirable. Once a social decision has been taken to make a certain investment (e.g. protect land from the consequences of a 1:100 year flood) the method is frequently used to compare different methods to achieving that goal. Complications arise, however, when the goal has broader social consequences, some of which have benefits and others may have costs. These have to be taken into account for the method to be effective but that comes down to valuing some of the benefits associated with the action, which was what the method was designed to avoid.

Box 7.13 Steps involved in evaluating eco-agri-food systems (‘value chain analysis’)

1. Set out the different stages of the value chain to be analyzed.

2. For each stage, identify the key social, economic and environmental indicators of performance.

   - Based on these indicators, identify economic impacts as well as the externalities and those relating to merit or demerit goods. The economic impact assessment not only serves to get the value-added at each stage but also includes who benefits from the production and where the costs are incurred.

   - Identify the social and environmental impacts that are desirable and that emerge as side effects, being both direct, indirect and induced impacts of economic activities. Estimate, when possible, economic values for these impacts.

Assess how these key indicators of performance are interconnected with each other. This can be done by developing a Causal Loop Diagram (CLD) (see, for example, Figure X), or a map of the system analyzed. In addition to the causal relations, space is important. As a result, the location of impacts is crucial (e.g. the proximity of economic activities to a river, and how the local population relies on such water are critical elements).

Carry out an assessment of the impact of economic activities, under various scenarios of policy interventions and practices utilized. This comprises the preparation of an assessment that considers simultaneously the social, economic and environmental impacts of economic activities, and the economic valuation of social and environmental externalities.

7.4.6 Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) expands the boundaries of the analysis beyond cost benefit or cost effectiveness results and allows the assessment of projects against a variety of criteria, including quantitative and qualitative indicators. In contrast to CBAs and CEAs, MCAs can be conducted in cases where multiple objectives and decision criteria exist (e.g. economic growth, employment creation and emission reduction). An example of the use of MCA related to agriculture was done by UNEP (2011) where a series of studies were conducted to evaluate adaptation options to deal with climate change. In the case of agriculture, the method took into account climate change impact as well as other factors9. Options considered were classified under the following categories: market-based financial instruments (21), public investment programs (18), regulatory instruments (11), information based instruments (16) and international cooperation programs (7). Each of the 73 individual options was evaluated with respect to criteria grouped in the following sets: public financing needs, implementation barriers, climate related benefits, economic benefits, environmental benefits, social benefits and political and institutional benefits. Using these to generate 19 criteria, each option is scored, using both objective and subjective scoring systems, and the scores are weighted and added to arrive at an overall score. The method was applied to a case study in Yemen. Governments around the world have used MCA to assist in evaluating projects and policies that have complex socio-economic and environmental impacts that are often hard to measure in monetary terms.

The main limitations to MCA relate to selecting which criteria to include and what weights to give to the different criteria; both can greatly impact the results of the exercise. It can also be difficult to convince policy makers of rankings based on MCA, which they may see as having a major subjective component.

In practice, all decisions relating to projects or policies involve policy makers taking account of multiple criteria, of which the benefits and costs as reported under a CBA would be one. They do not often employ formal MCA methods, however, and the process of arriving at a decision remains a political one. Almost always, policy makers will want CBA as part of their information set and in recent years we have seen the boundaries of CBAs expand, reaching closer to those of MCAs. This is the case of integrated or extended CBA (UNEP 2016), where externalities (social and environmental, as well as indirect and induced project outcomes, such as employment and income creation) are monetized and included in the assessment of the financial viability of projects10. The CBA method has also been used to include distributional considerations through the use of “weights” so transfers to a poor person are given a higher weight than the same transfer to a rich person or where employment has a

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[9] The case study is available at www.mca4climate.info.

[10] See for instance: https://www.iisd.org/project/SAVi-sustainable-asset-valuation-tool

direct additional benefit, thus reducing the labour cost of the project. If a project is being evaluated by developers or investors some factors such as distributional weights would not generally be used, but if it is being analysed by someone in the public sector, evaluating the options on behalf of society, then such weights would be relevant, as would all the externalities.

7.5 MODELLING TOOLS AND TECHNIQUES

Chapter 2 of this volume presents the rationale for using a systems approach to analyse the eco-agri-food system. In this section, several modelling techniques that can be used to carry out such systemic analysis are reviewed and discussed. These models can make use of the valuation techniques presented in section 7.3 and can also be used to support the evaluation methods described in section 7.4. For instance, simulation models can be utilized to estimate the total investment required to implement a project or reach a stated policy target, and to forecast the impact of such interventions on various indicators of interest, such as land cover. Subsequently, these results can be used to assess the economic viability of the investment (i.e. Cost Benefit Analysis). Specifically: (i) the investment amount can be used as a direct input for the CBA; (ii) the impact on land cover can be used to determine the extent to which ecosystem services are gained or lost, and also to determine the economic value of resulting change in ecosystem services. The latter value can be used as input to the CBA, as a potential avoided cost. An example is provided below.

The list of models reviewed here is not exhaustive. There is a large and growing literature on complex systems, and on the use of modelling approaches to analyse specific geographical contexts. Emerging approaches include Agent Based Models, which assess the ways in which economic agents (e.g. farmers, or economic actors in the eco-agri-food value chain) behave under various scenarios. With this in mind, we believe that our framework can help identify what should be included in more comprehensive modelling approaches and how the results from different approaches should be interpreted.

7.5.1 Land use and biophysical models

Biophysical models help planners decide how to manage the land and draw long-term plans for development, including the location of different activities and their impact on land, ecosystems and people. Such models can be a key input into the valuation of ecosystem services related to agriculture (see Section 1.4.1) and, in the case of land use models, spatial data are sometimes used as an input for the estimation and economic valuation of present and future ecosystem services. Products are often highly visual (e.g. maps, graphs, diagrams, and charts) but considerations of social and economic variables are in most cases qualitative.

Biophysical models require several types of data, often spatially explicit. Examples include data on land cover and on physical flows, both regarding inputs and outputs to production or other natural processes. For instance, in the context of water-related studies, data are required to estimate the supply of water (e.g. precipitation, evapotranspiration, percolation) and its consumption (e.g. land cover by type and by crop, specific daily or monthly water requirements by crop, population and resulting water consumption for sanitation). Estimating ecosystem services requires additional information, depending on the assessment. Examples include maps on soil and vegetation types, multipliers for carbon sequestration, by land cover and vegetation type. The availability of data for biophysical models is improving, especially from international databases (e.g. Group on Earth Observations, EXIOBASE 11). On the other hand, issues often arise in relation to the (low) resolution of maps and the validation of data on the ground (required to ensure the accuracy of the data extracted from the map). As a result, local validation is required, or customization of the model should be performed to better capture the local context.

A few examples are provided, on spatial planning, water supply and water requirements, and on the estimation of a variety of ecosystem services.

Spatial planning tools

Marxan and IDRISI Land Change Modeler are land use models, and are used to plot out optimal physical placement of economic activities, human settlements and other land uses. Practically, through the identification of trends (e.g. for population) and/or the use of assumptions for future land use change (e.g. land use per person), these models generate future land cover maps that optimize placement in space (e.g. with population being located close to urban centres or to infrastructure, or with agriculture land being in located in the most productive areas depending on soil types and water availability, or with the minimization of forest loss, and hence decline in carbon sequestration capacity and biodiversity loss). These models allow users to modify a specific set of parameters (e.g. hectares of land cover by type, or their determinants, such as population growth), but often do not include consideration to what the assumed/forecasted land use change means for socioeconomic effects or monetary valuation of loss/gain in natural capital assets.

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11 For more information see http://www.geoportal.org/ and http://www.exiobase.eu/

Water supply and water requirements (CROPWAT and SWAT)

CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO12. It facilitates the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. Concerning its application, CROPWAT informs the development of irrigation schedules for different management conditions and the calculation of required water supply for varying crop patterns. An example of the application of CROPWAT in Africa is done by Bouraima (2015) in Benin, where they estimated the crop reference and actual evapotranspiration, and the irrigation water requirement of Oryza sativa in the sub-basin of Niger River of West Africa.

The Soil and Water Assessment Tool (SWAT) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a continuous time model that operates on a daily time step at basin scale (Texas A&M University 2015). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods. It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land use is agriculture. It can also help in assessing the environmental efficiency of best management practices and alternative management policies.

Integrated Valuation of Environmental Services and Trade Offs (InVEST)

The Integrated Valuation of Environmental Services and Trade Offs (InVEST)13 is a family of models developed by the Natural Capital Project that quantifies and maps environmental services and supports (if required) their economic valuation using the techniques described above. InVEST is designed to help local, regional and national decision-makers incorporate ecosystem services into a range of policy and planning contexts for terrestrial, freshwater and marine ecosystems, including spatial planning, strategic environmental assessments and environmental impact assessments. There is also some discussion about applying InVEST to corporate level activities.

Artificial Intelligence for Ecosystem Services (ARIES)

ARIES is a web-based model that assists rapid ecosystem service assessment and valuation (ESAV)14. ARIES helps users discover, understand, and quantify environmental assets and the factors influencing their values, for specific geographic areas and based on user needs and priorities. ARIES encodes relevant ecological and socioeconomic knowledge to map ecosystem service provision, use, and benefit flows.

Multi-scale Integrated Models of Ecosystem Services (MIMES)

Scientists at the University of Vermont's Gund Institute developed the Multi-scale Integrated Model of Ecosystem Services (MIMES) for Ecological Economics15. MIMES uses a systems approach (in that it considers entire ecological systems, but not social and economic dynamics) to model changes in ecosystem services across a spatially explicit environment. The model quantifies the effects of land and sea use change on ecosystem services and can be run at global, regional, and local levels.

Strengths and limitations

There are several advantages to using biophysical models (see **Table 7.7**). First, they allow the analyst to estimate, and fully consider, the characteristics of a landscape, region or country and its carrying capacity. Second, the use of spatially explicit datasets and the generation of maps, allows visualization of past and future trends, and better estimates of the value of the ecosystem services that may be gained or lost.

Among the limitations is the lack of social and economic dimensions to the analysis, for which spatial data are generally less available and thus impact can only be inferred and not estimated directly. Furthermore, the analysis of land use changes and the resulting need for inputs to production (e.g. water) does not normally include the analysis of endogenous feedback loops, rendering the analysis comparatively static. In other words, the analysis does not consider that the expansion of agricultural land may lead to an increase in population, which may result in water consumption being higher than expected, and hence affect irrigation requirements and land productivity. As a result, the use of biophysical and spatially explicit models is primarily for scenario analysis rather than for supporting policy formulation and evaluation, where the anticipation of side effects is crucial. Finally, many of the parameters of the models are unknown and educated guesses have to be made about their values. This often makes the results they generate lacking in empirical data, a factor that highlights the strength of these models in policy formulation (where possible targets are set), rather than in policy assessment (where specific provisions are identified, and where a more in-depth assessment of local dynamics is required).

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[12] For more information, see: www.fao.org/land-water/databases-and-software/cropwat/en/

[13] For more information, see: www.naturalcapitalproject.org/InVEST.html

[14] For more information, see: http://aries.integratedmodelling.org/

[15] For more information, see: http://www.afordablefutures.com/services/mimes

Table 7.7 Potential contribution of Biophysical models to the assessment of the sustainability of the agri-food system (Source: authors)

Capital Base stocks	Produced capital	
	Human capital	
	Social Capital	
	Natural capital	Fully includes various types of natural capital stocks (e.g. soils, water resources, biodiversity)
Flows through the value chain	Capital input flows	Includes the estimation of ecosystem services (e.g. water provisioning) that could be used as input to production
	Ag and food goods and services flows	Estimates the output of agricultural activities (e.g. crop production)
	Residual flows	Estimates residual flows, such as ecosystem services affected by production (e.g. N&P and water quality)
Outcomes	Economic	
	Health	
	Social	
	Environment	Estimates changes to natural capital (e.g. deforestation)
Value chain impacts		
Spatial disaggregation		Spatially disaggregated, at the level of using GIS maps

7.5.2 Partial equilibrium models

At their simplest level, Partial Equilibrium (PE) models can be conceptualized as the interaction of supply and demand in a single market. PE models are a family of models that cover a single sector, generally at a high level of detail when compared to economy-wide models (e.g. CGE models). They range from single-sector single-company, or up to country models or single-sector multi-country models (FAO 2006). PE models typically use a "bottom-up" approach, placing emphasis on specific policy interventions (e.g. fiscal policies) or technology adoption. In both cases, PE models estimate the impact of such interventions on demand and production in a given sector.

Based on the new situation (policy scenario) and specific formulations and parameters explaining the strength of the relationship between demand and supply (i.e. elasticities), the PE model calculates a new equilibrium for the sector and provides output on a range of indicators (FAO 2006). With this background, several studies have expanded the boundaries of PE models to consider the indirect and induced impacts of production, with the goal to support policy and investment impact assessment. As an example, Callaway and McCarl (1996) compared the fiscal and welfare costs of achieving specific carbon targets through afforestation, and examined the welfare, fiscal, and carbon consequences of replacing existing farm subsidies, wholly or in part, with payments for carbon.

In addition to the detailed presentation of variables in the sector analysed, coverage of environmental, economic and social indicators can also be found in PE models. An example involving both economic and environmental aspects would be the application of pesticides. Estimating the damage done by different products is undertaken, often as part of a risk assessment, in which the risks are traded off against the benefits from the application. Certain products considered as highly toxic (e.g. endocrine disruptors) may be banned in certain locations if impacts are found to be present. In other cases, products may be permitted but with limitations on quantity, season etc. A review of the economic issues is given in Fernandez-Cornejo *et al.* (1998).

Partial equilibrium models generally require detailed information on a given sector, including: (i) economic accounting for revenues and costs of production, (ii) knowledge of production inputs (e.g. employment and labour cost, energy consumption and related expenditure, capital and material inputs and required investment), (iii) information on key determinants of demand and supply (e.g. the responsiveness of demand to price changes) and (iv) knowledge of the cost of interventions (e.g. technology investments) and their effectiveness. In the case of eco-agri-food system models, information for the estimation of revenues would be required on agriculture land, yield and prices, and concerning costs on infrastructure (e.g. mechanization and irrigation), labour, water and other inputs (e.g. energy, fertilizers and pesticides). When considering the value chain, additional data would be required on transport costs and the capacity to process food, including the revenues and costs (and their main determinants) of food processing. Given their high degree of customization, PE models, when data are available, can include a high degree of detail for the sector analysed.

Strengths and limitations

The advantage of PE models, which represent a piecemeal approach (in that these models focus only on part of the whole eco-agro-food process) is that the model can be highly customized and that the analysis is comparatively transparent, being tractable and relatively easy to carry out (see **Table 7.8** for their potential contribution to agri-food systems). In fact, detail can be added more easily than with macroeconomic (e.g. CGE) models. Further, data requirements are normally not extensive, and the model can be structured according to the availability of data. Conversely, the estimation of economic impacts across the whole value chain can be complex, spanning across several economic activities and disciplines of research, and data are not easy to obtain, interpret and use. As a result, if the item of interest is a particular activity (e.g. farm-related non-point pollution) it may be reasonable to focus on that component only.

The main limitation of PE models regards its sectoral and primarily economic focus, and whether assessing the impacts of policies and investments in isolation from other stages of the value chain (or in isolation from the sector and the economy as a whole) is reasonable, accurate and realistic. For instance, a technological breakthrough that lowers the cost of sugar production from cane may increase production and result in land clearance and other environmental impacts, which would be analysed as part of that process. But the lower costs of sugar production would also lower the costs of sugar as an input in the eco-agro-food process, making high sugar products cheaper and increasing problems of obesity and type II diabetes. This would normally not be considered in a partial equilibrium analysis that focuses on sugar production. This is because a PE analysis does not consider feedback effects, from the macro to the sectoral level. Similarly, given their limitation in addressing system-wide dynamics, PE models are not the best option to assess social equity concerns. While these models allow for the estimation of aggregate employment and income-related impacts, they generally fail to describe detailed distributional impacts of policy interventions and investments.

Table 7.8 Potential contribution of Partial Equilibrium models to the assessment of the sustainability of the eco-agri-food system (Source: authors)

Capital Base stocks	Produced capital	Includes capital stocks (e.g. assets), both in physical and monetary terms
	Human capital	
	Social Capital	
	Natural capital	May include certain types of natural capital stocks (e.g. land)
Flows through the value chain	Capital input flows	Generally includes infrastructure, labour inputs and certain ecosystem services
	Ag and food goods and services flows	Considers both inputs and outputs
	Residual flows	Can estimate both waste and other residuals
Outcomes	Economic	Estimates value added, taxes, subsidies and possibly wages, also considering trade dynamics
	Health	
	Social	
	Environment	Can estimate changes to natural capital (e.g. deforestation, affecting land cover)
Value chain impacts		It can include various stages of the value chain
Spatial disaggregation		

7.5.3 Computable General Equilibrium (CGE) models

A general equilibrium approach models supply and demand across all sectors in an economy. Analysis is typically conducted using computable general equilibrium (CGE) models (see, for instance, Lofgren and Diaz-Bonilla [2010]). CGE models are a standard tool of analysis and are widely used to analyse the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets, or contain menus of different tax, subsidy, quota or transfer instruments (Wing 2004).

CGE models utilize input-output tables (Leontief, 1951), which can also be utilized as standalone models for more static analysis, and which represent inputs and outputs of several economic activities (e.g. the amount of labour, energy and material input required to produce a unit of production output). Equations are estimated that explain the relationship between inputs and outputs of a given process, or sector (e.g. how much energy is required for a unit of output, given the use of a specific technology in the production process). In other words, the model uses productivity multipliers that serve for the calculation of the output values given a specific set and quantity of inputs, or it estimates the required inputs for a given value of output (Tcheremnykh 2003). While being most often primarily focused on economic flows, CGE models have in several cases been extended to include environmental impacts of production and consumption on water, land and air. As a result, these models can assess the impacts of changes such as climate or trade liberalisation on outputs and prices across all sectors as well as on the incomes of different groups in society.

There are numerous applications focusing on the agricultural sector that use such models, for instance, the effect of climate change and water scarcity on crops and livestock, as well as on the income of poor groups in society. See for example Skoufakis *et al.* (2011), or the MAGNET model of the European Commission, which has been used to assess the impacts of agriculture, land-use and biofuel policies on the global economy (Boulanger *et al.* 2016). Other applications for the agriculture sector include the assessment of socio-economic impacts of improving agriculture water use efficiency (Liu *et al.* 2017), analyzing climate change related impacts on water availability and agriculture production (Ponce *et al.* 2016), and the estimation of the outcomes of public investments in irrigation infrastructure and training agriculture labour (Mitik and Engida 2013).

CGE models optimize utility for economic actors, and the three conditions of market clearance, zero profit and income balance are employed to solve simultaneously for the set of prices and the allocation of goods and factors that support general equilibrium. Practically, this means that CGE models assume that the demand and supply for a product and service always match, through the identification of a price that satisfies both consumers and producers. As opposed to partial equilibrium models, CGEs are in general ‘top-down’, meaning that variables such as food production are determined by parameterised equations (e.g. balancing demand and supply through prices), rather than considering individual technologies. The underlying assumption is that if there is demand (e.g. through consumption), there will be production as well. Bottom up models estimate instead what production level is feasible and at what costs, depending on the technology available and utilized.

CGE models require a large amount of detailed data on across all economic sectors, including factors of production and international trade. Traditional data inputs for CGE models are the Social Accounting Matrices (SAMs), and the System of National Accounts (SNA).

Strengths and limitations

The main advantages of CGE models include the estimation of direct and indirect impacts of policy interventions and investments, and the use of an economy-wide approach. As a result, interdependences across sectors, and countries, are taken into account. The variables included in CGE models are, among others, sectoral consumption and production, wages, household income and inflation, as well as trade. Nowadays most agricultural sector analysis involving taxes or subsidies or changes in trade regimes would make use of CGE models. This results in CGE models being used very often to assess equity impacts, especially in terms of income distribution across income classes and employment groups. On the other hand, CGE models do not generally support the assessment of non-monetary dimensions of equity, such as access to services and resources. CGE models are useful in examining the relationship between climate change and agriculture, where increases in temperature and precipitation are expected to lower yields for some crops by significant amounts. The size of the effect varies from one region to another and with trade the implications for price and welfare in different regions will vary. Among the key factors are the relevance of the sector in the economy (e.g. production and contribution to GDP, as well as employment), its reliance on trade and exposure to changing weather conditions, the extent to which support is provided through subsidies (Randhir and Hertel 2000), and the relevance of a given food product in household consumption (Hertel *et al.* 2010). **Table 7.9** lists the potential contribution of CGE models to the assessment of the sustainability of food systems.

CGEs have significant limitations. First the modelling is complex and depends on a number of parameters whose values are uncertain. This emerges for instance when data are not available, but also when the underlying input-output tables and the Social Accounting Matrix, which are often generated every five or ten years, are outdated (e.g. when policy analysis is required for the period 2018-2025, but the underlying data are from the year 2012). Hence the results have a high level of uncertainty. Second, the level of detail of CGE models is often not adequate to support the analysis of sectoral dynamics in detail. Third, CGE models often suffer from the lack of supply-side constraints (especially physical ones), in that they assume that extra output can be achieved and that scarcity is not a concern (Gretton 2013). In reality the boundaries of the analysis should be expanded to account not only for the availability of labour and capital, but for natural resources as well. Practically, CGE models lack the explicit representation of biophysical stocks and flows and rely on underlying assumptions on equilibrium and the maximization of welfare that may not represent reality.

Table 7.9 Potential contribution of CGE models to the assessment of the sustainability of the eco-agri-food system (Source: authors)

Capital Base stocks	Produced capital	Includes capital stocks (in monetary terms)
	Human capital	Includes labour productivity
	Social Capital	
	Natural capital	Models for agriculture would include land cover
Flows through the value chain	Capital input flows	Includes capital and labour, models focused on agriculture may include certain ecosystem services
	Ag and food goods and services flows	Considers both inputs and outputs, generally with less detail than PE models
	Residual flows	Could include GHG emissions
Outcomes	Economic	Estimates value added, prices, taxes, subsidies and wages, also considering trade dynamics
	Health	
	Social	Estimates impacts on consumption and income for various household groups
	Environment	
Value chain impacts		It can include various stages of the value chain
Spatial disaggregation		Spatial disaggregation is found for multi-country models, at the national level

7.5.4 System Dynamics (SD)

Systems Thinking (ST) is a methodology for "seeing systems" and assessing policy outcomes across sectors and actors, as well as over time (Meadows 1980; Randers 1980; Richardson and Pugh 1981; Forrester 2002). ST can help to assess how different variables in a system interact with each other to shape trends (historical and future). While Systems Thinking is qualitative, System Dynamics is a quantitative methodology. In fact, it aims to define causal relations, feedback loops, delays and non-linearity to represent the complex nature of systems (Sterman 2000). It does so by running differential equations over time (i.e. representing time explicitly, with days and months). In contrast to CGE and PE models, System Dynamics models do not optimize the system (i.e. they do not estimate the best possible setup of the system to reach a stated goal). Instead, these are causal-descriptive models used to run "what if" simulations.

Created by Jay W. Forrester in the late 1950s, System Dynamics (SD) allows a modeler to integrate social, economic and environmental indicators in a single framework of analysis. SD models are based on the assumption that structure drives model behaviour and uses causal relationships to link variables. By way of further explanation, SD models include feedback loops (a series of variables and equations connected in a circular fashion). The feedback loops generate non-linear trends that ultimately determine the trends forecasted. This is what is meant by saying "structure" (i.e. the variables and, more importantly, the feedback loops in the model) determine "behaviour" (i.e. the trends forecasted over time). In all other modelling approaches that are linear (i.e. with no feedback loops), the "behaviour" is primarily driven by the data used (not by the equations, or the structure of the model).

SD approaches provide a more explicit representation of the factors driving demand (e.g. population divided by age cohorts, income divided by household group, and prices) and supply (for agriculture production these factors include land productivity as affected by soil quality, mechanization, labour, production inputs, water availability and weather conditions), merging biophysical and economic indicators as stocks and flows. The complexity of a system is represented using Causal Loop Diagrams (CLD) and models can be customized to analyse the socioeconomic implications of different actions across sectors (social, economic and environmental) and actors (e.g., households, private sector and the government), within and across countries.

A CLD can be used to explore and represent the interconnections between key indicators in the sector or system of interest (Probst and Bassi 2014). Examples are shown in Figure 7.5 as well as Figure 2.6 in Chapter 2 . John Sterman states, "A causal diagram consists of variables connected by arrows denoting the causal influences among the variables. The important feedback loops are also identified in the diagram. Variables are related by causal links, shown by arrows. Link polarities [a plus or minus sign indicating the positive or negative causality between two variables] describe the structure of the system. They do not describe the behaviour of the variables. That is, they describe what would happen if there were a change. They do not describe what actually happens. Rather, it tells you what would happen if the variable were to change" (Sterman 2000). The creation of a CLD has several purposes: first, it combines the team's ideas, knowledge, and opinions; second, it highlights the boundaries of the analysis; third, it allows all the stakeholders to achieve basic-to-advanced knowledge of the dynamics underlying the sector or system analyzed.

The pillars of SD models are feedback, delays and non-linearity.

- 'Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself' (Roberts et al. 1983). Feedbacks (also called feedback loops in systems modelling) can be classified as positive or negative. Positive (or reinforcing) feedback loops amplify change, while negative (or balancing) counter and reduce change.

- Delays are characterized as "a phenomenon where the effect of one variable on another does not occur immediately" (Forrester 2002). Sometimes becomes difficult to attribute certain effects to specific causes, as cause and (perceived) effect are distant in time. For example, when there is an increase in the use of fertilizers, it takes time for nitrogen and phosphorous to reach water bodies and negatively impact the ecological integrity of a bay or river basin.

- Non-linear relationships cause feedback loops to vary in strength, depending on the state of the system (Meadows 1980), and determine how structure defines behaviour. For instance, with agriculture yield being influenced simultaneously by the type of seeds used, nutrients, climate, and land use practices, each embedded in a variety of feedback loops, non-linear behaviour emerges from the model.

SD models inform policy formulation and assessment, and also monitoring and evaluation. By running "what if" scenarios, SD can inform policy measures that may improve several indicators at once (e.g. providing affordable food supply while generating employment and reducing forest loss), rather than estimating the optimal policy package. Turner et al. (2016) conclude that SD provides a useful framework for assessing and designing sustainable strategies for agriculture production systems. Typical applications include the analysis of systemic challenges for smallholder farmers and conservation agriculture in South Africa (Von Loeper et al. 2016), and the assessment of policy interventions in the context of national Green Economy Strategies ((Deenapanray & Bassi 2014; Musango et al. 2014; UNEP 2015).

SD models typically need data on socioeconomic and environmental variables, depending on the boundaries of the model. Practically, more data across social, economic and environmental indicators are required than in the case of other modelling approaches, but the level of depth and disaggregation of the data is lower than what is normally required by biophysical, partial and general equilibrium models. These data are sourced from multiple disciplines and databases and checked for consistency (or harmonized) for inclusion in the integrated model. Further, it is worth noting that SD models start simulating in the past (e.g. year 2000) and, unlike other methodologies (e.g. econometric modelling), rely on historical data only for the parameterization of the simulation model, not for the creation of forecasts. In other words, while econometric models investigate the correlation among historical time series to determine how future trends may be shaped, correlation factors in SD models are not an input for simulations; instead, these emerge from the simulation of endogenous feedback loops (based on causality) and exogenous parameters (Sterman 2000).

Strengths and limitations

The main strengths of SD include the ability to estimate strategy and policy impacts for a specific project or policy and for society, and how these impacts unfold dynamically over time. In fact, the simulation of scenarios with quantitative systems models allows decision-makers to evaluate the impact of selected interventions within and across sectors as well as economic actors, using social, economic and environmental performance indicators (both stocks and flows). Second, the simulation of causal descriptive models helps to simplify the complexity of the eco-agri-food system (because it more transparently shows all the relationships existing across modelled variables, and how changes in one variable are reflected in all the others), and can evaluate the short vs. longer-term advantages and disadvantages of the analysed interventions. In other words, it reduces complexity. Third, a causal descriptive model can capture new and emerging trends (or patterns of behaviour) emerging from the strengthening (or weakening) of certain feedback loops, and help identify potential side effects and additional synergies. This is particularly useful in assessing physical and economic impacts, and how these are interconnected (such as in the case of access to resources and services). In other words, SD models can estimate the strength of a feedback loop and forecast changes that may emerge in the future. For instance, the price of a limited resource may be low when such resource is abundant. As a result, the balancing feedback loop that leads to resource efficiency would be weak (i.e. the resource is so cheap that investments that improve resource efficiency may not be bankable). On the other hand, as consumption increases in the future and the stock of such resource declines, its price would increase. In this situation the balancing feedback loop of resource efficiency would become stronger, because a higher price justifies investments that reduce resource consumption. Practically, SD models can forecast whether feedback loops that were weak in the past may gain strength in the future, and whether feedback loops that were strong in the past may become weak in the future.

There are also limitations to the use of SD models. First, the effectiveness of a CLD and SD model is directly related to the quality of the work and the knowledge that goes into developing them. Two aspects need to be considered: the source of the knowledge embedded in the model, and the skills of the modelling team. On the former, multi-stakeholder perspectives should be incorporated and cross-sectoral knowledge is essential to correctly identify the causes of the problem and design effective interventions. In addition, the selection of relevant variables and the way in which they are mapped (most often in a group model building exercise) is crucial. On the skills of the modelling team, building valid SD models requires extensive experience to develop a sufficiently detailed and representative description of the system (i.e. the dynamic hypothesis). The lack of experience increases the difficulty to correctly identify and estimate the underlying feedback structure of the system. A second limitation of SD models is the correct identification of boundaries of the system, not an easy task. Errors in identifying the boundaries of the model (i.e. what variables and feedback loops to include/exclude) may lead to biased assessments of policy outcomes, overstating or underestimating some of the impacts across sectors and actors. Third, SD models are highly customized, and are better suited for use in a specific geographical context. In other words, this is not an ideal approach for assessing trade dynamics among several countries; it is an approach better suited to analysing national dynamics, and possibly linkages between two or three countries. It is not well suited to carry out assessments on trade that involve five or more countries. Finally, concerning implementation, the development of a SD model requires a substantial amount of interdisciplinary knowledge. The data needs depend on the level of detail being modelled and increase with every new subsystem that is added. As a result, SD models are generally focused on horizontal integration (i.e. across sectors) rather than vertical integration (i.e. adding sectoral detail). As a result, SD models are weaker than CGE models in the analysis of the distributional impacts of policy intervention, generally including less detail on economic activity, household and income groups.

Table 7.10 Potential contribution of System Dynamics models to the assessment of the sustainability of the eco-agri-food system (Source: authors)

Capital Base stocks	Produced capital	Includes capital stocks (e.g. assets), both in physical and monetary terms
	Human capital	Includes labour productivity
	Social Capital	Can include qualitative indicators representing governance and accountability
	Natural capital	Can include several stocks of natural capital
Flows through the value chain	Capital input flows	Includes capital and labour, as well as ecosystem services
	Ag and food goods and services flows	Considers both inputs and outputs, generally with less detail than PE models
	Residual flows	Can estimate both waste and other residuals
Outcomes	Economic	Estimates value added, taxes, subsidies and wages, within a specific geographical context (e.g. trade dynamics across countries are normally not captured)
	Health	Can include nutrition and diseases
	Social	Can estimate impacts on consumption and income, and access to ecosystem services, but with less detail than CGE models
	Environment	Can estimate changes to natural capital (e.g. deforestation, affecting land cover)
Value chain impacts		Possible, but with a lower degree of disaggregation when compared to PE and CGE models
Spatial disaggregation		Spatial disaggregation is found, mostly at sub-national level (e.g. provinces)

Table 7.11 summarizes the key contribution of the methodologies and models reviewed to the analysis of the sustainability of the eco-agri-food system. The rows of the table are elements of the evaluation framework presented in Chapter 6. More details for each technique follow, with an overview of their strengths and weaknesses and applicability to the eco-agri-food system.

Table 7.11 links the analytical tools used in the evaluation of eco-agri-food systems to the systemic approach presented in Chapter 2, and the capital accounting framework laid out in Chapter 6 and developed by the UN in its Inclusive Wealth Report (UNU-IHDP and UNEP 2014). The models use, in different ways, data on the stocks of produced human, social and natural capital as well as data on changes in these stocks through flows. Policies and actions then estimate the outcomes that track changes in economic, health, social and environmental indicators.

Table 7.11 Overview of the main characteristics of the modelling techniques reviewed, in relation to the evaluation framework (Source: authors)

		Land use and biophysical models	Partial Equilibrium	Computable General Equilibrium (CGE)	System Dynamics (SD)
Capital Base stocks	Produced capital		Includes capital stocks (e.g. assets), both in physical and monetary terms	Includes capital stocks (in monetary terms)	Includes capital stocks (e.g. assets), both in physical and monetary terms
	Human capital			Includes labour productivity	Includes labour productivity
	Social Capital				Can include qualitative indicators representing governance and accountability
	Natural capital	Includes various types of natural capital (e.g. soils, water resources, biodiversity)	May include certain natural capital stocks (e.g. land)	Models for agriculture would include land cover	Can include several stocks of natural capital
Flows through the value chain	Capital input flows	Includes the estimation of ecosystem services (e.g. water provisioning) that could be used as input to production	Generally includes infrastructure, labour inputs and certain ecosystem services	Includes capital and labour, models focused on agriculture may include certain ecosystem services	Includes capital and labour, as well as ecosystem services
	Ag and food goods and services flows	Estimates the output of agricultural activities (e.g. crop production)	Considers both inputs and outputs	Considers both inputs and outputs, generally with less detail than PE models	Considers both inputs and outputs, generally with less detail than PE models
	Residual flows	Estimates residual flows, such as ecosystem services affected by production (e.g. N&P and water quality)	Can estimate both waste and other residuals	Could include GHG emissions	Can estimate both waste and other residuals

Outcomes	Economic		Estimates value added, taxes, subsidies and possibly wages, also considering trade dynamics	Estimates value added, prices, taxes, subsidies and wages, also considering trade dynamics	Estimates value added, taxes, subsidies and wages, within a specific geographical context
	Health				Can include nutrition and diseases
	Social			Estimates impacts on consumption and income for various household groups	Can estimate impacts on consumption and income, and access to ecosystem services, but with less detail than CGE models
	Environment	Estimates changes to natural capital (e.g. deforestation)	Can estimate changes to natural capital (e.g. deforestation, affecting land cover)		Can estimate changes to natural capital (e.g. deforestation, affecting land cover)
Value chain impacts			It can include various stages of the value chain	It can include various stages of the value chain	Possible, but with a lower degree of disaggregation when compared to PE and CGE models
Spatial disaggregation		Spatially disaggregated, at the level of using GIS maps		Spatial disaggregation is found for multi-country models, at the national level	Spatial disaggregation is found, mostly at sub-national level (e.g. provinces)

7.6 AN INTEGRATED MODELLING APPROACH FOR THE ECO-AGRI-FOOD SYSTEM

In order to carry out an assessment of the social, economic and environmental impacts of production and consumption in the eco-agri-food system, knowledge integration is required. No single model can address all the needs of various stakeholders, some of which are concerned with macroeconomic trends (e.g. employment creation at the national level) while others are more preoccupied with localized impacts (e.g. nutrition and water quality). The TEEB approach proposes a modelling framework that integrates several modelling approaches. In other words, it makes use of the main strengths of each approach, and by linking them it removes some of their weaknesses.

There are several gaps that need to be addressed in the way quantitative assessments are being carried out. Specifically, more systemic analyses are required in order to assess policy outcomes across sectors and actors (considering all capitals and their interdependencies), as well as over time. Such analyses would allow the analyst to anticipate the emergence of side effects, leading to the formulation of complementary policy intervention, and ultimately resulting in improved resilience and sustainability of the eco-agri-food system.
Mainstream modelling approaches are typically designed to answer a specific policy question, and, in order to excel in one task; these models simplify the complexity of the system. In the context of TEEBAgriFood, this highlights a disconnect between our ‘systemic’ thinking and available models. To ensure that the wider evaluations support the decision-making process for sustainable eco-agri-food systems effectively, emphasis should therefore now be put on the development and use of models that allow for a fuller representation of the complexity of the eco-agri-food system, including the many causes and mechanisms responsible for the emergence of problems as well as for the success (or failure) of proposed solutions.

Considering the various methods and models available to analyse the eco-agri-food system and its parts, several opportunities for using a complementary approach emerge. System Dynamics could be utilized as a knowledge integrator, incorporating the key features of various evaluation methods, and providing a systemic and dynamic view of the problem under consideration and its possible solutions. Practically, a SD model could make use of inputs from biophysical models, and integrate these with those received from economic models, possibly allowing for a spatially explicit analysis. This modelling approach would then complement the analysis carried out with input-output, partial equilibrium and general equilibrium models, providing information on both capital base stocks, flows through the value chain and outcomes. Specifically, this modelling approach can make use of the higher level of detail included in partial equilibrium models as well as of the larger detail on economic activities included in CGE models; coupling these with the explicit spatial representation of biophysical models provides an integrated assessment that includes social and environmental indicators and related dynamics. This analysis would capture feedbacks existing across social, economic and environmental indicators, better assessing policy impacts in highly interconnected and rapidly changing environments.

A high degree of customization is required to create this type of model. This is to account for (i) local circumstances, (ii) the tacit and explicit local knowledge, and (iii) the identification and understanding of the priorities of local decision makers. Specifically, it is crucial to use local knowledge sources in the identification of causal relations and feedback loops. Further, the analysis must provide information on indicators that decision makers deem important to increase policy impact[16](Rouwette and Franco 2014). **Box 7.14** illustrates an application of integrated modelling to the eco-agro-food system with an example from Tanzania.

Box 7.14 Illustration of integrated modelling for the eco-agri-food system, Kilombero Tanzania

In 2010, the Government of Tanzania launched the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) initiative as a public-private partnership dedicated to ensuring food security, reducing poverty and spurring economic development in Tanzania’s Southern Corridor (SAGCOT Centre 2013). TEEB launched a study to create and compare alternative quantitative scenarios for land management of the Rufiji River Basin in Tanzania, using a systems approach.

The TEEB project for Tanzania combined: (a) spatial planning tools, (b) biophysical ecosystem service models, (c) socioeconomic models based on System Dynamics, and (d) nonmarket environmental valuation methods. Together, these tools and methods have been used to carry out a holistic analysis of development impacts and land-use change (planned or otherwise) and the socioeconomic implications of such change and translated these into spatial outputs. Practically, four modelling methods and tools were combined and incorporated in an integrated model.

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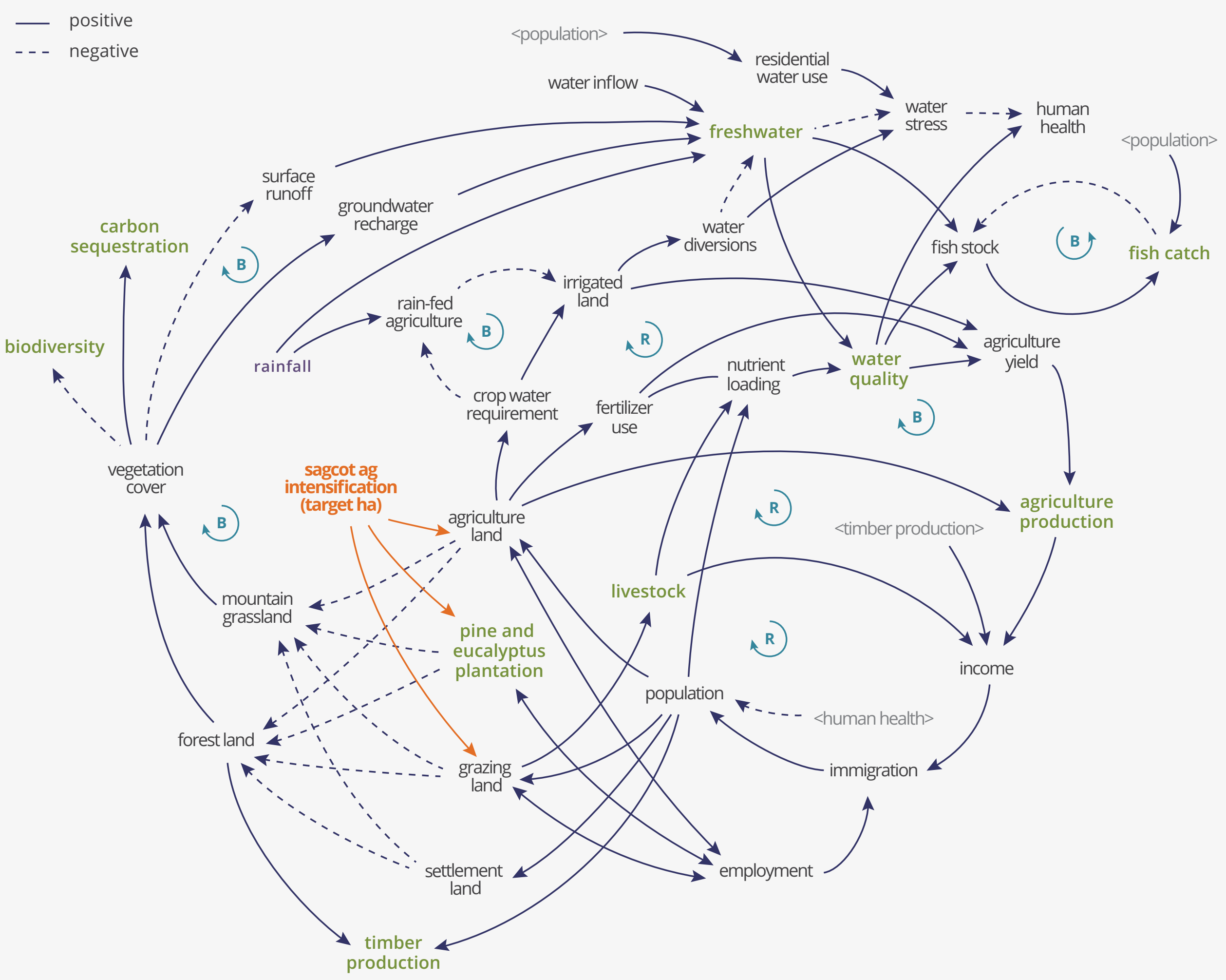
[16] “Local knowledge refers to information and understanding about the state of the bio-physical and social environments that has been acquired by the people of a community which hosts (or will host) a particular project or programme.” (Baines et al. 2000).

Figure 7.5 Causal Loop Diagram (CLD) of the study area, emphasizing the impacts of implementing the SAGCOT agriculture intensification plan (Source: authors)



Given that water availability is a key enabler of agriculture production and one of the main drivers of well-being, CROPWAT was used to estimate irrigation requirements and SWAT was used to estimate water yield and runoff. In order to fully account for the potential impact of upcoming investment strategies, socio-economic analysis is also required that complements the work done with CROPWAT and SWAT. This is because population dynamics and policy responses (e.g. deforestation) can greatly affect the effectiveness of national policy. Finally, in order to inform this policy discourse, the economic valuation of ecosystem services was carried out. This is to identify and estimate the potential loss of natural capital under the baseline scenario, and as well as what could be gained under alternative scenarios.

Figure 7.5 presents the CLD that was created through a group model building exercise for representing the main drivers of change in the Kilombero basin. There are four main feedback loops that underlie the dynamics of the area studied. The first (1) causes the expansion of agriculture land, the second loop (2) is represented by the increase in employment that is caused by the expansion of agriculture land under policy scenarios, such as in the case of SAGCOT, the third loop (3) highlights the relevance of vegetation (which increases groundwater recharge and lowers surface water and runoff) and the fourth (4) shows the importance of the type of crops planted and their respective water requirements.

The analysis carried out with this suite of models, integrating biophysical and socio-economic tools, indicates that the combination of fostering cluster development, intensifying and diversifying agriculture production, and improving water efficiency allows for maintaining the positive outcomes on employment, income and production that are expected from SAGCOT, by avoiding the negative consequences related to water availability, social issues and ecosystem integrity would have in the BAU scenario (see **Table 7.12**). Coupled with sustainable agriculture practices, which would limit the use of chemical fertilizers, and thereby avoiding water pollution, this strategy would maximise the performance of the system across social, economic and environmental indicators, ensuring long term social and environmental sustainability and economic viability for the agriculture sector in the Kilombero valley[17].

7.7 SUMMARY AND CONCLUSIONS

The eco-agri-food sector is of great economic and social importance. It has been subject to many changes over recent years, often with negative impacts on the environment and on vulnerable groups. At the same there have been policy initiatives to address these negative impacts and to make the system more consistent with the goals of sustainable development.

This chapter has been devoted to presenting the toolbox at our disposal to review the impacts of the functioning of the eco-agri-food sector and to enable policy makers to compare different policies and measures, especially when faced with evidence of inadequate performance of some parts of the system.

The complexity of the system must be acknowledged; agriculture not only involves the growing of crops and husbandry of livestock, but is also part of a configuration in which the activities of production, processing, distribution, consumption and waste disposal are all key components. In the past these linkages have tended to be ignored when formulating and appraising agricultural policies. The chapter shows the importance of the linkages and feedbacks between these activities and why they need to be seen as an integrated framework.

On the environmental side there is an important link between agriculture and food production and the ecosystems in which such activities are embedded. These ecosystems provide key services to the agri-food system and in turn the way in which the latter works has an effect on the ecosystems. Consequently it is important to understand these linkages, which requires an appreciation of the different ecosystem services and their relation to food production, as well as the subsequent steps in the agri-food system.

As far as the tools are concerned a distinction is made between the valuation, in monetary terms, of impacts of the agri-food system and of policies that target that sector; and a wider evaluation of the system that takes account of other factors of importance, such as equity, human health and sustainability. The monetary valuation of impacts is organized around the idea of externalities, which are made up of impacts of the eco-agri-food system that are not accounted for in market transactions. The chapter gives several examples of such externalities and ways of estimating the costs they generate on society. There are several tools at our disposal for undertaking these estimations; each has its strengths and weaknesses and each is best suited to the valuation of particular externalities.

The data collected from the estimation of externalities can be used to appraise a policy option in conjunction with tools such as cost benefit analysis, cost effectiveness analysis, partial equilibrium modelling and general equilibrium modelling. With such tools the costs of the policy and the costs associated with the externalities are combined to obtain an economic measure of the net impacts of the policy compared to the case of no policy or an alternative policy.

For the wider evaluation of the functioning of the eco-agri-food system and of different policies a number of other tools are presented. These include life cycle analysis, propensity scoring methods, value chain analysis, multi-criteria analysis, merit good assessments and system dynamics. In these cases the analyst obtains information on a range of physical impacts of a given eco-agri-food system under a given set of regulations and compares these with the impacts under an alternative set of regulations or other changes in the eco-agri-food system. Each tool has its strengths and weaknesses and is best suited to specific problems, which are discussed in the chapter.

With all the tools discussed there is a key role for the biophysical modelling of the links between different parts of the eco-agri-food system and of the ways in which these parts respond to different regulatory instruments, such as taxes or charges, subsidies, prohibitions etc. Some tools use the modelling to obtain the physical indicators that are their end product, while others use the modelling as the basis for physical values that are then valued in monetary terms. In both

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[17] Quantitative results are provided in the project factsheet: Managing Ecosystem Services In Rufiji River Basin: Biophysical Modeling And Economic Valuation, available at www.teebweb.org/areas-of-work/teeb-country-studies/tanzania

cases the end product is only as reliable or as effective as the underlying biophysical modelling, which is often quite weak and uncertain.

There is a lot of work to be done to undertake comprehensive evaluations of different policies and measures related to the functioning of eco-agri-food systems. Ideally one should be able to say with some confidence what are the externalities associated with each euro or dollar spent on a given kind of food, produced, distributed and disposed of in a given way. We are making progress toward that goal and with the changes in practices proposed in this chapter, which lays the foundations for future work in this area and provides the analyst with an overview of the toolbox at her disposal, we may be more successful.

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CHAPTER 8

APPLICATION OF THE TEEBAGRIFOOD FRAMEWORK: CASE STUDIES FOR DECISION-MAKERS

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SUMMARY

Chapter 8 demonstrates an initial exploration of the TEEBAgriFood Evaluation Framework through ten existing case studies that focus on various aspects of the value chain: agricultural management systems, business analysis, dietary comparison, policy evaluation and national accounts for the agriculture and food sector. Various issues within the Framework are explored, including the need for future modifications and adaptations. The case studies have helped identify opportunities to both expand particular aspects of the Framework for comparisons as well as to introduce spatial and temporal contexts. The explorations within this chapter are an introduction to a process that will continue to expand, as lessons are learned with each application of the Framework.

CONTENTS

FIGURES, TABLES AND BOXES

CHAPTER 8

8.0 KEY MESSAGES

- Chapter 8 demonstrates an initial exploration of the TEEBAgriFood Evaluation Framework through 10 existing case studies that focus on various aspects of the value chain: agricultural management systems, business analysis, dietary comparison, policy evaluation and national accounts for the agriculture and food sector.
- Various issues within the Evaluation Framework are explored, including the need for future modifications and adaptations. The case studies have helped identify opportunities to both expand particular aspects of the Framework for comparisons as well as to introduce spatial and temporal contexts. With each application and adaptation of the Framework, it becomes robust and comprehensive. Thus, the explorations within this chapter are an introduction to a process that will continue to expand as lessons are learned with each application of the Framework.
- The chapter illustrates how the Framework can be adapted to capture all stocks and flows of natural, human and social capital through the entire value chain of eco-agri-food systems so that they can be better reflected in national accounts.
- There is need to extend the scope of the Framework to examine trade-offs at each stage of value chain as found in various examples, especially when comparing management systems and evaluating policy scenarios.
- There is no single example included where the entire value chain was explored; therefore, there is a compelling case to develop and apply the TEEBAgriFood Framework further in order to better understand all positive and negative externalities in an eco-agri-food system complex.
- A comprehensive and full-scale application of the TEEBAgriFood Framework can help address policy questions. For example, to help determine the best agricultural management system, the Framework can help analyse contrasting systems, which can help develop policy responses that incentivise better management. The Framework can be used by consumers to weigh dietary choices and better understand the health implications of their current food consumption patterns, and to evaluate food footprints.
- There is need to redefine priorities and plan further testing of the Framework in order to better consider entire value chain and to better evaluate capital (natural, social, human) and stocks (flow of ecosystem services) in the agriculture sector. Complete application will require a considerable amount of time and resources to populate the Framework. A limited number of case studies are explored here due to data restrictions.

CHAPTER 8

APPLICATION OF THE TEEBAGRIFOOD FRAMEWORK: CASE STUDIES FOR DECISION-MAKERS

8.1 INTRODUCTION

This chapter seeks to help navigate the complexity of contemporary eco-agri-food systems and to assess their many dimensions, taking account of both positive and negative externalities (social, human and environmental) as well as ecological dependencies. The preceding chapters have provided the TEEBAgriFood Evaluation Framework (Chapter 6) and reviewed diverse methods of valuing and evaluating sustainability in the eco-agri-food value chain (Chapter 7). In this chapter, we present five distinct "families of application" for which the Framework could be useful, and needs adaptation for at least five groups of stakeholders (See **Table 8.1**). The five families are, (i) agricultural management systems which are defined by the type of practices and production systems at farm level and may include organic, conventional, natural farming, high or low input systems etc., (ii) Agricultural products include analysis of farm products such as organic milk and conventionally produced milk, (iii) Dietary comparisons family include diverse set of diets, for example, Mediterranean diet, plant based diet, vegetarian diet etc., (iv) Policy evaluations include different farm and agricultural related public or business sector policies at national, global or regional scale, and (v) National accounts application may examine differences between standard national accounts and adjusted national accounts after internalising externalities.

At this early stage in the development of TEEBAgriFood as an approach, complete examples of the application of the Framework do not exist. We have thus sought to present in **Table 8.2** a snapshot of 10 case studies[1], illustrating a diversity of approaches that seek to assess different aspects (i.e. positive and negative externalities) of the eco-agri-food value chain in a range of different geographic contexts. In some cases, existing studies provide sufficient detail to be mapped onto the Framework directly, showing how it can be applied or adapted. In other cases, it was necessary to carry out a review of the literature and bring additional information into the case study from other sources, in order to explore the utility of the Framework.

Table 8.1 Five "families of application" as identified by TEEBAgriFood, and their relevant stakeholder groups

Family of application	Stakeholders
Agricultural management systems	Agricultural producers, Farming communities, Consumers and public, Policy makers
Agricultural products	Agricultural producers, Farming communities, Consumers and public, Policy makers
Dietary comparisons	Consumers and public, Policy makers
Policy evaluations	Public, Policy makers on all levels
National accounting for the agriculture and food sector	Public, Policy makers on national levels

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[1] Full details of each case study are provided in a separate Annexure, available online at www.teebweb.org/agrifood/scientific-and-economic-foundations/chapter-8-annexure.

Table 8.2 A snapshot of the 10 case studies presented in this chapter

Family of application	Case study	Aspects along agri-food value chain	Comparison	Geographic scope	Valuation methods and evaluation models
Agricultural management systems	1. Rice management practices	Agricultural production	Ecosystem functions, services and impacts at farm and landscape level under agroecological versus conventional rice management systems and practices	Philippines, Cambodia, Senegal, USA, Costa Rica, Vietnam, Malaysia, Indonesia	Direct market valuation, multi criteria analysis, cost benefit analysis
	2. Organic and conventional agriculture	Agricultural production	The value of a suite of ecosystem services under different management systems	New Zealand, Global	Direct market valuation, production function approach, avoided cost
Agricultural products	3. Beef production-grass fed versus grain fed	Agricultural production, manufacturing, Distribution	Impacts and benefits of different beef production systems, at farm, processing and consumption levels	United States	Direct market valuation, market price
	4. Palm oil study	Agricultural production, manufacturing	Key natural capital impacts of palm oil production	11 leading producer countries	Market price, avoided cost, damage cost, integrated approaches (Life cycle analysis)
Dietary comparisons	5. Welfare and sustainability effects of diets	Household consumption	Multiple sustainability dimensions of dietary recommendations	France	Life cycle analysis, cost benefit analysis, avoided cost
	6. Ten different diet scenarios ranging from meat based to vegetarian diets	Agricultural production, Manufacturing, Distribution, Household consumption	Bio-physical impacts of different diets on land use and carrying capacity	United States	Land use and biophysical models, Life cycle analysis
Policy evaluations	7. Pesticide tax case study	Agricultural production, Household consumption	External costs of pesticide, as could be used to inform policy	Thailand	Dose response function, Partial equilibrium model
	8. China Ecosystem Assessment	Agricultural production	Reduction of natural disaster risk by restoring forest and grassland, impacts on livelihood options and poverty	China	Direct market valuation, bio-physical models, InVest model
National accounting for the agriculture and food sector	9. Agricultural development in Senegal	Agricultural production, Manufacturing, Distribution, Household consumption	Socio-economic and environmental impacts of investment in different types of agriculture development	Senegal	System dynamics and biophysical models, cost benefit analysis
	10. Environmental-economic national accounts	Agricultural production, Manufacturing, Distribution, Household consumption	Bio-physical costs and benefits of the agriculture sector	Australia	Market price methods, Computable General Equilibrium

8.1.1 Commentary on the evolving nature of the TEEBAgriFood Evaluation Framework

This chapter presents lessons learned from drawing on existing evidence and studies to populate the TEEBAgriFood Evaluation Framework, with reference to the five "families" of application described above. The case studies presented here demonstrate both the potential and the limitations of the Framework, notably with respect to spatial and temporal dimensions. With each application and adaptation of the Framework to specific circumstances, the Framework should become more robust and comprehensive. The exploration in this chapter may be seen as part of a process that will continue, as further lessons are learned with each application.

The rest of the chapter is organised as follows. Section 8.2 provides the scoping criteria and data collection process and explains how each example was selected, section 8.3 summarises the 10 applications under five different families and reviews the lessons learned from the application of the Framework, section 8.4 highlights social inequities, section 8.5 provides challenges and limitations of the Framework, and section 8.6 offers some closing thoughts. It should be noted that all Tables featured in this chapter have been generated by the authors.

8.2 APPLYING THE TEEBAGRIFOOD EVALUATION FRAMEWORK

The TEEBAgriFood framework facilitates the comparison of systems that generate ecosystem services - the goal being to minimize negative externalities and facilitate positive ones – thereby contributing to increases in stocks of produced, natural, human and social capital, and thus to human well-being. A comprehensive listing of ecosystem services can be found in many recent texts including the TEEB (2010) and, more recently, CICES (EEA 2018). TEEBAgriFood thus seeks to focus on the capacity of different systems in the agriculture and food sector to contribute to increases in stocks of produced, natural, human and social capital, thus to human well-being.

8.2.1 Scoping and criteria

Selection criteria

A criterion for the selection of examples described in this chapter is found in Table 3. First, our intention was to examine studies that captured all positive and negative externalities of the eco-agri-food system and was not solely focused on productivity. For example, if a given study examined different management systems and provided both monetary and non-monetary (bio-physical) estimates of impacts, then we selected it for further analysis. In addition, we focused on studies that examined changes in stocks of produced, social, human or natural capital and that studied the impacts on human well-being. We carefully searched for and selected examples that fall under one of the five families of applications of the framework – management systems, food products, different diets, policies, and national accounts. We also looked for examples that captured externalities of at least one aspect of the value chain (i.e., production, manufacturing, distribution and household consumption) in detail.

The 10 case studies used various valuation methods and evaluation models, which are listed at the beginning of the case study and described in detail in the previous chapter 7.

Case studies described in this chapter were selected during a two-round process. First, all shortlisted examples were evaluated using the selection criteria in Table 8.3. Then they were further examined using in-depth criteria in Table 8.4. These set of criteria were used to make a comprehensive decision on the selection of cases, to ensure a high quality and diversity of the examples.

We considered geographic balance and selected examples covering Africa (Senegal), Oceania (Australia, New Zealand), Asia (China, Vietnam, Malaysia, Indonesia, Thailand, the Philippines), Europe (France), and North America (USA).

Not all desired criteria could be uniformly met; further details are provided in the online Annexure.

8.3 CASE STUDIES BY FAMILY OF APPLICATION OF THE TEEBAGRIFOOD EVALUATION FRAMEWORK

Each example from the five families of application is presented with a brief introduction, key objectives, approaches and methods used and key results. The biophysical and/or monetary information in each case study is shown using the TEEBAgriFood Evaluation Framework (detailed in Chapter 6). Recommendations for further research and potential policy questions along with lessons learned in applying the evaluation framework end each of the 10 case studies.

Table 8.3 Selection criteria for case studies

	Scope	Criteria
1	Primary scope	Does the example provide a holistic assessment of agriculture or food system? (not just production or consumption, but including the positive and negative externalities connected with these)
		Does it address at least one of the five groups of applications of TEEBAgriFood Framework (please indicate the group)? Comparisons of: • Management/production systems, (i.e., organic versus conventional) • Products, (i.e., grass-fed beef versus beef from feedlots) • Diets, (i.e. Mediterranean diet versus fast-food diet) • Policy scenario, (i.e. soda tax, results before and after application) • National accounts? (i.e. taking stock of environmental goods and services from agriculture versus conventional accounts)
		Is it documented in a peer-reviewed article or a well-respected source of grey literature? (provide reference or link and contact information).
2	Level of assessment	Does it address at least one of aspect of the food value chain: For example, production, processing & distribution or consumption?
		Does it compare at least two contrasting systems?
		Does it focus on the level of whole systems or individual practices?

Table 8.4 In-depth selection criteria

1	Thematic scope	Does the example include produced, natural, social, and/or human capital?
		Does it include monetary values, biophysical and/or social indicators?
2	Method used	Is the evaluation method used in the assessment quantitative or qualitative?
		Are economic or bio-physical models used?
		Quantitative: correlation, econometric models, biophysical models, simulation, cost-benefit analysis, cost-effectiveness analysis, etc.
		Qualitative: Evaluating choices against ethical and social decision principles and values (rights, justice and social equity, poverty reduction, human health, ecological, and cultural values, etc.).
		Integrated approaches and methods: Life Cycle Analysis, cost benefit analysis, multi-criteria analysis etc.
3	Scale of assessment	What is the scale of assessment (local, national, regional, global)?
4	Geographic scope	Does this apply globally or to a specific region/country?
5	Perspectives on sustainability	At what level (e.g. farm, business, society) does the application propose a sustainable alternative? To what extent are different forms of capital addressed; for example, is social and human capital included in the analysis?

8.3.1 Agricultural management systems

Two examples are presented in this section: i) agro-ecological versus conventional rice management practices, and ii) organic versus conventional agriculture

8.3.1.1 CASE STUDY 1: Rice management practices: agro-ecological versus conventional

Rice is central to the food security of half the world (FAO 2014). Rice production provides a range of ecosystem services beyond food production alone. For example, rice systems support cultural values in many regions of the world, can provide important habitat for wildlife, and are capable of sustaining natural pest control and their inherent fertility, under certain management systems (Settle *et al.* 1996; Halwart and Gupta 2004;). At the same time, rice production has been linked to a range of adverse environmental impacts such as greenhouse gas (GHG) emissions, air and water pollution as well as freshwater consumption.

The question of interest is how to reduce trade-offs and enhance synergies between generating positive externalities (rice production, cultural benefits) and minimizing negative ones (such as water use levels and pollution), such that the well-being of farmers, and society at large is enhanced.

The TEEB rice study (Bogdanski *et al.* 2016) set out to identify those farm management practices that offer the best options to reach synergies, and reduce trade-offs between different management objectives in rice agro-ecosystems in five case study countries around the globe: the Philippines, Cambodia, Senegal, Costa Rica and the United States (California). The analysis refers to rice production, on the one hand, and a range of different externalities, i.e., an environmental impact or ecosystem service, on the other, to show potential trade-offs or synergies between the two.

A scenario analysis was carried out to show the effect of different management objectives. For example, if Senegal was to change all its irrigated lowland rice systems from conventional management to water-saving rice production systems, society would save about US$ 11 million in water-related health and environmental costs, while at the same time increasing yields and farm incomes. Alternative, ecological pest management and the importance of cultural ecosystem services provided by rice systems is also highlighted in the study, although not quantified or included in scenarios. The results have confirmed the need for practice and location specific typologies to show the full range of external benefits and costs.

In a broad sense, this case study shows that by assessing farming systems as a whole, taking negative and positive externalities into focus along with standard production metrics, it is possible to highlight key synergies and trade-offs. Often where trade-offs are expected in rice production systems, alternative management practices may result in win-win outcomes.

Table 8.5 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. The agricultural output in terms of rice production, income and purchased inputs was captured in the study at farm-level in the agricultural production side of the value chain. Other provisioning services (for example, energy generation from rice husks) were monetized using direct market valuation. Regulating services (nutrient cycling, pest control, genetic diversity etc.) or supporting services (such as habitat provisioning) were also assessed where data was available. Cultural ecosystem services such as heritage, tourism, access to traditional rice varieties were also captured in the study. The study also describes (but does not measure) impacts on human health due to pesticide exposure, and impacts on ground water and air. These are reflected in the changes in human and natural capitals, respectively by using cost benefit analysis.

Policy questions that a TEEBAgriFood Framework-testing study can inform

Given the critical importance of rice to food security around the world, governments often have many policies developed to support the consistent, low-cost supply of rice to consumers. In many cases, these involve government-setting of rice commodity prices, and subsidies for inexpensive inputs—in particular—pesticides. If all externalities were to be included in prices, this would be turned around, as pesticides would become much more expensive (see for example, case study 7 (pesticide tax), and Praneetvatakul *et al.* 2013). The challenges for policy makers include:

- In determining rice policy, all the benefits and costs of different rice production systems should be taken into consideration (including water and nutrient flows, health impacts, cultural values and greenhouse gas emissions).

- As research has shown, inexpensive prices for agricultural chemicals lead to intensive use in rice, which then leads to pest resistance and the need for even more inputs. Policy on prices of pesticides should be designed to reflect these negative externalities and encourage alternative modes of pest control.

Table 8.5 Case study 1 (rice): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production	Manufacturing and processing	Distribution, marketing and retail	Household consumption
Outcomes (change in capital)				
Natural capital	🟩 Impact on groundwater and surface water quantity and quality	▨	▨	▨
Produced capital	▨	▨	▨	▨
Human capital	🟩 In disability adjusted life years (DALYs), Health costs related to pesticide use, Moderation of extreme events	▨	▨	🟩 Dietary variability
Social capital	▨	▨	▨	▨
Flows				
Outputs				
Agricultural and food production	🟦 Rice yield	▨	▨	▨
Income / operating surplus	🟦 Income	▨	▨	▨
Purchased inputs to production				
Labour	🟦 Wages	▨	▨	▨
Intermediate inputs (fuel, fertilizer, etc.)	🟦 Fertilizers, fuel	▨	▨	▨
Ecosystem services				
Provisioning	🟦 Habitat provisions, energy from husk	▨	▨	▨
Regulating	🟧 Watershed management, Freshwater saving, Nutrient cycling, Soil fertility enhancement, Pest control, Groundwater recharge, Genetic diversity	▨	▨	▨
Cultural	🟩 Cultural Heritage, Maintenance of rice terraces, Tourism, Traditional rituals and spiritual experiences related to rice system, Traditional knowledge on rice cultivation	▨	▨	🟩 Access to and consumption of traditional rice varieties
Residual flows				
Food waste	▨	▨	▨	▨
Pollution and emissions (excess N & P, GHG emissions, etc.)	🟦 Water pollution from pesticides, Water pollution from fertilizer	▨	▨	▨
	🟩 Eutrophication			

🟩	Descriptive information available
🟧	Quantitative information available
🟦	Monetized information available
▨	Not included in study

As this study suggests, there are many potential “savings” that can be applied to conventional rice production systems, for example in improved water and nutrient management, in reduced use of agricultural inputs, in the potential for integrating fish in rice paddies when pesticides are not present. Such savings could permit greater support for farmer training and sharing on ecological approaches to rice production, such that the cost of rice does not need to increase in order to produce the same or higher yields more ecologically.

Lessons learned

The focus of this study was specific practices in rice production in five countries (Bogdanski *et al.* 2016). Practices of course are very numerous and their collective impacts on ecosystem services are nuanced and complex. Yet for decision-makers to use a TEEB-like analysis to understand in what ways a rice production system can generate positive externalities and minimize the negative, a way of synthesizing these impacts and providing a trade-off analysis is needed. Equally, such a synthesis would bring the opportunities for synergies to the attention of decision makers and point out where trade-offs can be minimized and yields can be maintained while ecosystem services are being generated and enhanced. The framework does not, as yet, have capacity to point to these areas of trade-offs and synergies, that may be of great interest to decision-makers. In the literature for the rice feeder study, there is a lack of monetary valuation methodologies of agro-ecosystem benefits. A strength of the framework is that it goes beyond quantitative and monetary measures and gives room to qualitative discussion as well. However, to do trade-off analysis accurately will require data and studies that provide a comprehensive data set that goes beyond food production alone (as is typically done in agronomic studies). Often studies comparing yield and other ecosystem services are missing. This also counts for environmental studies that might omit agronomic values. In addition, environmental and socio-economic benefits and costs are often studied in isolation from each other, despite them being closely interconnected.

8.3.1.2 CASE STUDY 2: Organic versus conventional agriculture

A comparison of organic and conventional agricultural systems at field, region and global scale is presented here. In this study, 12 different ecosystem services associated with both systems in New Zealand agriculture are explored, including ‘provisioning services’ – i.e. food and other raw materials – as well as intangible, non-marketed ‘regulating’, ‘cultural’ and ‘supporting’ services (Sandhu *et al.* 2015). The study also estimates the economic value of these ecosystem services for both organic and conventional systems based on experimental assessment and direct market valuation using market prices and avoided cost method.

The total economic value of ecosystem services in organic fields ranged from US $1610 to US $19,420 ha− 1yr− 1 and that of conventional fields from US $1270 to US $14,570 ha− 1 yr− 1 (Sandhu *et al.* 2008). All ecosystem services including food production values were higher in organic fields as compared to the conventional ones. This is due to the higher market price for organic produce, and comparable yields in both systems. Regulating and supporting services were found to be higher in organic than the conventional agriculture (pollination, biological control, nutrient cycling etc.). Two ecosystem services out of 12 investigated (biological control of pests and mineralization of plant nutrients) were then extrapolated to 110 countries in 15 global regions to illustrate the potential magnitudes for farming in those regions (Sandhu 2015). This approach can help improve understanding of the potential contribution of non-marketed ecosystem services to global agriculture. It does not advocate large-scale conversion to organic practices. However, if only 10 per cent of the global arable land utilised such ecosystem services-enhancing techniques, then this study shows that the total value of ecosystem services can surpass the total cost of inputs (Sandhu 2015). However, this study did not consider regional climatic conditions, social-political factors, crop management changes and their market prices, or the rate of uptake of organic farming practices by farmers while extrapolating the results (Sandhu 2015).

Table 8.6 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. This study identifies trade-offs between two alternative production systems by comparing ecosystem services that include provisioning, regulating and cultural services. Organic agriculture depends on enhanced above and below ground biodiversity, which provides pollination services, biological control of pests and diseases, nutrient cycling etc. It can take time for such processes to reach optimum levels; therefore, there could be some trade-offs in the level of production and profitability in the interim. The study quantified various ecosystem services and provided monetary estimates in two production systems using direct market valuation and an avoided cost approach (Table 6). It captured visible and invisible flows in terms of 12 ecosystem services at the production side only. However, it did not quantify changes in natural, physical, social and human capital. The impact of different management systems on land, as a form of natural capital is described.

Table 8.6 Case study 2 (organic/conventional agriculture): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production		Manufacturing and processing	Distribution, marketing and retail	Household consumption
	Organic	**Conventional**			
Outcomes (change in capital)					
Natural capital	Land improvement, biodiversity structure	Land degradation			
Produced capital					
Human capital					
Social capital					
Flows					
Outputs					
Agricultural and food production	Grains yield	Grains yield			
Income / operating surplus	Profits	Profits			
Purchased inputs to production					
Labour	Wages	Wages			
Intermediate inputs (fuel, fertilizer, etc.)	Fuel, irrigation etc.	Fuel, irrigation, fertilizer, pesticide use			
Ecosystem services					
Provisioning	Raw material, bioenergy	Raw material			
Regulating	Soil formation, Nitrogen fixation, Pollination, Biological control of pests, Mineralization of plant nutrients, Soil fertility, Hydrological flow, Shelterbelts	Soil formation, Nitrogen fixation, Pollination, Biological control of pests, Mineralization of plant nutrients, Soil fertility, Hydrological flow, Shelterbelts			
Cultural	Land improvement, biodiversity structure	Aesthetics			
Residual flows					
Food waste					
Pollution and emissions (excess N & P, GHG emissions, etc.)					

Higher value	Lower value	
🟩	🟩	Descriptive information available
🟧	🟧	Quantitative information available
🟦	🟦	Monetized information available
⬜	⬜	Not included in study

Policy questions that a TEEBAgriFood Framework-testing study can inform

The following policy questions address the need to increase food production without impacting human and environmental health.

- Given the significant value of some non-marketed ecosystem services, especially in organic production systems, how can markets be built to recognise these values, and the contribution of farmers in providing them?
- Recognizing the large international trade in conventional agricultural inputs, is it possible to build alternative markets for ecosystem services that sustain production, and at what scale (i.e. in one state, or global or regional)?
- The market share of organic products continues to increase, but supply often lags demand. What policies can be put in place to optimize the supply-demand equation for organic foods?
- What would be the health benefits to farmers, farm workers and consumers of policies promoting greater reliance on ecosystem services in production over conventional inputs? (See case study 7 on pesticide taxes in Thailand, for some indication.)

Lessons learned

Monetary valuation of ecosystem services can help to draw attention to the ecosystem services that are neither valued nor recognized in farmer income. The current TEEBAgriFood Framework does quite adequately address the positive externalities of different agricultural systems, although the scope for providing comparisons needs to be further developed. In further elaborations of this type of study (and for the Framework), it would be valuable to reflect on time dimensions in the comparisons. Ecosystem services in organic agriculture may require longer than one season to provide full levels of service (biological control, for example, or the building of soil fertility through cover crops), and yet can be reduced through one season of pesticide application or misuse of fertilizers. The Framework may serve to encourage more research on other aspects (such as nutrition, health and social equity) not yet covered, even within the production sectors.

8.3.2 Business analysis

Two examples are presented in this section: i) grass-fed versus grain-fed beef, and ii) palm oil.

8.3.2.1 CASE STUDY 3: Grass-fed versus grain-fed beef

Current conventional systems produce tremendous quantities of meat at relatively affordable prices, yet many key questions about this practice arise through a TEEB-like assessment. In this case study we have drawn from multiple sources to draw the outlines of the visible and invisible flows in two contrasting beef production systems: grain-fed and grass-fed beef in the United States. Many issues related to the beef industry are well known, so we highlight only one from each food system stage that are less known, and then focus on possible policy considerations (more details can be found in the online Annexure).

Production (and associated waste); Pollution impacts: Animals produce significant amounts of greenhouse gases such as methane and carbon dioxide during digestion. By some estimates, when emissions from land use and land-use change are included in the calculation, the livestock sector accounts for 18 per cent of CO2 deriving from human-related activities (Steinfeld *et al.* 2006). Producing 1kg of cheap beef generates as much CO2 as driving 250km in an average European car or using a 100W bulb continuously for 20 days. Animal agriculture is also responsible for roughly 37 per cent of all human-induced methane emissions, which has a global warming potential 23 times that of carbon dioxide (Steinfeld *et al.* 2006). The relative difference in enteric fermentation (where methane is produced in the rumen as a digestion process) and manure emission levels per head between grain-fed and grass-fed beef is not well understood. However, there are important production differences, and areas requiring careful contextualization.

Grain-fed beef production: It has been suggested that fertilizer use to support animal agriculture will generate nearly twice as much N2O as would its use for crops destined for direct human consumption. This is thought because “N2O is first produced when the fertilizer is applied to the cropland for growing the animal feed grain and then is produced a second time when the manure-N, which has been re-concentrated by livestock consuming the feed, is recycled onto the soil or otherwise treated or disposed of” (Davidson 2009).

Grass-fed beef production: If well-managed and promoted by use of increased permanent cover of forage crops, pastured livestock can reduce soil erosion and emissions while sequestering carbon in pasture soils (Teague *et al.* 2016). However, grass-fed cattle in the Midwestern United States must be fed hay in the winter months when pastures are under snow.

Table 8.7 Case study 3 (grass vs. grain-fed beef): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production		Manufacturing and processing	Distribution, marketing and retail	Household consumption	
Outcomes (change in capital)						
Natural capital	Land degradation, water pollution		Air and Water pollution			
Produced capital						
Human capital					Grain-fed beef: Increased likelihood of rapid evolution and proliferation of antibiotic-resistant strains of bacteria.	Grass fed beef: lower in calories, healthier omega-3 fats, more precursors for vitamins A and E, higher levels of antioxidants, 7 x beta-carotene
Social capital					Grain-fed beef: Social fabric of communities undergoes significant change as industrialized farm animal operations replace family farms	
Flows						
Outputs						
Agricultural and food production	Grain-fed beef: substantial contribution to US national economy, production	Grass-fed beef: small but growing portion of national beef production	Grain-fed beef: Vertical integrators in meat processing business Grass-fed beef: largely locally owned services; these generates seven times that value to the local community			
Income / operating surplus						
Purchased inputs to production						
Labour						

Intermediate inputs (fuel, fertilizer, etc.)	⬜		⬜	⬜
Ecosystem services				
Provisioning	Grain-fed beef: highly productive but inherently inefficient, benefiting from subsidies to corn and soy.	Grass-fed beef: variable but often higher costs of production	🟦	no clear-cut, consistent taste differences between grain-fed and grass-fed beef
Regulating	Grain-fed beef: Excessive nutrient loading, water contamination from CAFOSs known to cause simplification of ecosystems and services	Grass-fed beef: well managed grazing may support soil organisms and grassland diversity	🟦	🟦
Cultural	Interest and pride in grass-fed ranching culture is strong			Consumers have been shown willing to pay higher prices for grass-fed beef
Residual flows				
Food waste	⬜		⬜	⬜
Pollution and emissions (excess N & P, GHG emissions, etc.)	Grain fed beef: Animal waste from CAFOs not uniformly treated; often applied to cropland in ways that are detrimental to soil health and water nutrient loads.		Grass-fed beef: Careless management of grazing land can contribute to ecosystem degradation, while holistic management can contribute to healthy grasslands	⬜

🟩	Descriptive information available
🟧	Quantitative information available
🟦	Monetized information available
⬜	Not included in study

Both the production and transportation of beef have costs and greenhouse gas implications. In addition, managed pastures may require intensive inputs of fertilizers and other amendments. Industrial agriculture will always perform better when looking at quantity of beef produced per land area than more agroecological approaches. Yet, what causes global warming is the total net emission of greenhouse gases per area, regardless of yields. Grain-fed livestock's overall contribution to greenhouse gases is substantial, and intensive meat production has vastly increased in the last few decades (Carolan 2011). Efficiencies in production will not offset increases in total emissions, if livestock production continues to expand in the same way it has through industrial animal feedlot operations.

Processing and distribution (and associated waste); Value capture: There are distinct economic disparities between farm communities that include industrial farm animal production units and those that retain locally owned farms where animals are finished on-farm (Pew Charitable Trusts and Johns Hopkins Bloomberg School of Public Health 2008). This study used direct market valuation to estimate the impact of local farms on the community. It has been estimated that every dollar earned on a locally-owned farm generates seven times that value to the local community. In contrast, industrial farm animal facilities have a much lower multiplier effect because their purchases of feed, supplies, and services tend to leave the community, going to suppliers and service providers mandated by the vertical integrators in the meat processing business (ibid.).

Consumption (and associated waste); Health Impacts (Nutrition, Lifestyle diseases, Antibiotic resistance, etc.): As noted above, an infectious agent that originates at an industrial farm animal facility may persist through meat processing and contaminate consumer food products in homes or restaurants, resulting in potentially serious disease outbreaks far from the facility (Pew Charitable Trusts and Johns Hopkins Bloomberg School of Public Health 2008). Proliferation of antibiotic resistant bacteria is a major health concern.

Animal sewage from industrial farm animal facilities is generally stored in lagoons intended to reduce pathogenic elements, but even the best managed are estimated to kill off only 85 to 90 per cent of viruses, and 45 to 50 per cent of bacteria (Carolan 2011).

The available evidence comparing grass-fed versus grain-fed beef production brought together in this case study, from a multitude of recent reports, highlights the need to integrate often diverse data to carry out a TEEB analysis (Table 8.7). The lack of common metrics makes analysis difficult; production values are economically based, whereas production and consumption impacts are based on health metrics (few of these, as yet, have been quantified). Synthesizing the resulting synergies and trade-offs and integrating the results remains challenging.

Policy questions that a TEEBAgriFood Framework-testing study can inform

The global food system is geared towards enabling high levels of consumption of cheap meat. A few key potential policy changes include:

- Taking stock and assigning value to all the negative and positive externalities of beef production systems, including health concerns over antibiotic resistance, worker safety, animal welfare, impacts on local and often low-income communities, and healthy diets, to begin. It may be impossible make policy decisions that promote specific outcomes on any one of these concerns without having impacts on others--this helps further highlight the need for an underlying systems model for which the impacts of different policy interventions could be played out. A holistic model of the farming systems should be able to indicate not just the costs, but also the benefits of the contrasting production systems. For example, a complete assessment of the implication of single policy measures, such as banning antibiotic use in beef production, or removing subsidies for animal feedstocks would give policy makers the ability to perceive "ripple effects" on other parts of the food system.

- Supporting more sustainably produced beef through mid-sized diversified farming systems; building support for transitions to diets and food systems that incorporate smaller quantities of higher quality meat consumption.

- Probing where, along the food system, policy measures can be most effectively applied. For example, Bittman (2011) notes a history and precedence in the United States where revenues for farm support measures were raised on taxes on food processors. If indeed it is the "food giants" of food processors (conceivably including concentrated animal feeding operations, or CAFOs) that have profited mightily from subsidized corn and soy, thus they might be asked to share more the cost of negative externalities.

Lessons learned

While many aspects of beef production fit well into the TEEBAgriFood framework, it is not clear where to place some others that may be more global or "underlying". This is a larger challenge within the TEEBAgriFood framework, as it remains difficult to differentiate between "visible and invisible flows" when examining contrasting examples. The overall impact of meat production on global food security is an example of this. Collectively, cattle, pigs and poultry consume roughly half the world's wheat, 90 per cent of the world's corn, 93 per cent of the world's soybeans, and close to all the world's barley not used for brewing and distilling (Tudge 2010). The discourse on how to address the challenges of feeding a growing world population often focuses on a perceived imperative to simply increase production; yet simple production of calories is not the fundamental issue, as world agricultural production of calories is more than sufficient to feed each person more calories than are needed per day. The extent of croplands devoted to producing grain and soy-based animal feed is estimated at about 350 million hectares; in the United States an estimated 50% of all grain produced goes to animal feed. Using productive croplands to produce animal feed imposes a negative force on the world's potential food supply (Foley *et al.* 2011). The conversion of tropical rain forests in Latin America to produce soy feed for animal agriculture, much of it in other continents including the USA, is equally an issue of social values in conflict. Multi-criteria analysis method could be used in such studies to provide policy relevant advice to the meat industry, where several bio-physical (GHG emissions, impacts on land use, water use etc.) and social (consumer perceptions, public health etc.) criteria exist.

8.3.2.2 CASE STUDY 4: Palm oil

Raynaud *et al.* (2016) quantify and monetize the key natural capital impacts of palm oil across the 11 leading producer countries, with a focus on Indonesia, the world's largest palm oil producer. The study quantifies human capital impacts and also captures visible and invisible natural capital costs linked to the growing, milling and refining stages of palm oil production. It does not include transportation, food processing and consumption.

Palm oil production in the 11 countries assessed has a natural capital (e.g., land degradation, loss of biodiversity, air and water pollution) cost of $43 billion per year compared to the commodity's annual value of $50 billion. Producing one tonne of crude palm oil (CPO) has a natural capital cost of $790 while one tonne of palm kernel oil costs $897. The results also show that underpayment and occupational health impacts have a total human capital cost of $592 per full-time employee, or $34 per tonne of palm oil and $53 per tonne of palm kernel oil.

Table 8.8 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. This study covered some elements at the production and processing side of the framework as demonstrated by Table 8.8. It captured visible and invisible flows in terms of ecosystem services at the production side only using avoided cost and damage cost methods. It captured changes in stocks of produced, natural and human capital and provided information of the health impacts. A complete analysis using the TEEBAgriFood evaluation framework could help steer policy concerning the clearing of tropical forest, international trade with largest consumer of palm oil (e.g., India) and the subsequent health issues from palm oil consumption in India.

Policy questions that a TEEBAgriFood Framework-testing study can inform

Given increasing demand of palm oil, an application of the TEEBAgriFood Evaluation Framework suggests following questions that can be addressed at policy level.
How can markets be built to recognise the value of natural, social and human capital, and the contribution of small holders in providing them?
How can policy help to internalize negative externalities of the palm oil production sector to minimize losses of natural and human capital?
Recognising the global trade in palm oil, is it possible to map all externalities and be able to identify the stakeholders who should pay for these (or be compensated for external benefits provided)?
What policies can be put in place to manage supply-demand of palm oil production?

Lessons learned

The palm oil study focused largely on production and distribution and evaluated impacts on natural capital and human health. Various social and natural components were not explored, including ecosystem services (soil erosion control, biodiversity, water regulation, other agricultural production that support subsistence livelihood etc.). The TEEBAgriFood framework can help illuminate more of the costs and benefits associated with distribution, help inform policy options such as impacts of land clearing on the local and global environment and help assess health impacts in countries that are largest consumers of palm oil.

Table 8.8 Case study 4 (palm oil): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production	Manufacturing and processing	Distribution, marketing and retail	Household consumption
Outcomes (change in capital)				
Natural capital	Land degradation, loss of biodiversity	Air and water pollution, loss of biodiversity		
Produced capital				
Human capital	Health impacts of fuel use, fertilizer application, and pesticide application, Health impacts from air pollution from forest/ biomass burning, Occupational health	Health impacts due to GHG emissions in processing		Health impacts in consumers
Social capital				
Flows				
Outputs				
Agricultural and food production	Fruit yield	Oil production		
Income / operating surplus	Income from yield	Income from Palm Kernel Oil, Income from Crude Palm Oil		
Purchased inputs to production				
Labour	Wages of casual and permanent workers			
Intermediate inputs (fuel, fertilizer, etc.)	Cost of fertilizer, pesticide etc.			
Ecosystem services				
Provisioning	Other crops such as rice for home consumption, cattle etc.	Methane capture from Palm Oil Mill Effluent for energy		
Regulating	Soil erosion, Water quality impacts of sedimentation, Water quality impacts of sedimentation, Land conversion and loss of biodiversity, including endangered species			
Cultural	Land dispossession and potential displacement of communities, Workers' rights violations, Loss of livelihood alternatives			
Residual flows				
Food waste				
Pollution and emissions (excess N & P, GHG emissions, etc.)	Terrestrial, marine, and freshwater ecosystem toxicity of pesticides and fertilizers, GHG emissions from fertilizer production, pesticides and other raw materials, Change in C stocks due to deforestation	GHG emissions from Palm Oil mill effluent		

🟩 Descriptive information available

🟧 Quantitative information available

🟦 Monetized information available

⬜ Not included in study

8.3.3 Dietary comparison

Two examples are presented in this section: i) diets in France, ii) ten diet scenarios and carrying capacity of agricultural land in US.

8.3.3.1 CASE STUDY 5: Welfare and sustainability effects of diets in France

The chosen study assessed French dietary recommendations in light of multiple sustainability dimensions such as taste, cost, welfare effect, deaths avoided, GHG emissions and acidification (Irz 2016).

A model of rational behaviour is developed by Irz (2016), building on microeconomic theory of the consumer under rationing (dietary constraints), with the goal of identifying diets compatible with both dietary recommendations and consumer preferences. Six different sustainable diet recommendations based on consumer guidelines in France are considered in this study. The dietary recommendations assessed are small adaptations of the current French diet, a 5% relative variation in the level of constraint of its baseline level. The constraints derive from nutrient based (salt intake, saturated fat acids, (SFA)) and food-based (fruit and vegetables, meat), health (added sugar) and environmental (CO_2 emissions) that estimates the effects in terms of chronic disease prevalence and mortality was applied. The effect on environmental indicators was estimated as well, making use of a Life Cycle Analysis (LCA) approach. These estimates take into account each stage of the production, transformation, packaging, distribution, use, and end-of-life of products.

The percentage change in consumption of the 22 food groups was calculated for each of the different restrictions. Due to the complementarity and substitutability among the food products captured in the model, a decrease in meat consumption of 8 grams/day (-5%) results in relatively important changes in consumption of starchy foods (-2.2%) and dairy products (+3.4%). Also, within subgroups substitutions occur, for example more fish (+7.5%) and less eggs (-3.3%). The restriction on only red meat results in smaller adjustments in food consumption.

The overall benefits and cost-effectiveness of the recommendations were calculated, taking into account economic, health and environmental elements. The result emerged that most restrictions are very cost-ineffective. The next step is a more complete cost-benefit analysis, in which the benefits and costs of the measures can be considered jointly. Valuing the positive effects with the social cost of carbon (32 Euro/ton), the value of an avoided death (240,000 Euro), justifies spending considerable amounts to promote the recommendations targeting Fruits & Vegetables (F&V), Salt, Saturated Fatty Acids (SFA), added-sugar and red meat. With higher social cost for carbon (185 Euro/ton) and a value for an avoided death closer to the value of a statistical life (1 million Euro), the benefits of targeting GHGs and consumption of all meat appear to be cost-effective as well. This way of reasoning makes it possible to rank the recommendations to be promoted.

The model developed in this study weighs the taste cost (or short-term welfare costs) incurred by consumers against the health and environmental benefits induced by their adoption. Based on the complete cost-benefit analysis the authors conclude that; i) measures focused on intakes of F&V, SFA, sodium, and to some extent, added-sugar, provided that they lead to at least a 5% change in the consumption of the targeted food or nutrients, would be a valuable investment; ii) informational measures to promote a reduction of red meat or all meat consumption would be valuable investment only for relatively high values of CO_2. A last conclusion: the values of health benefits induced by dietary recommendations are often much greater than those of environmental benefits (except in the case of a very high CO_2 price).

Table 8.9 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. Various elements are covered for the consumption side of the value chain in this study. Outcomes for human capital are also described and captured in monetary terms.

Table 8.9 Case study 5 (diets in France): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	**Agricultural production**	**Manufacturing and processing**	**Distribution, marketing and retail**	**Household consumption**
Outcomes (change in capital)				
Natural capital	▒	▒	▒	▒
Produced capital	▒	▒	▒	▒
Human capital	▒	▒	▒	Value of avoided deaths (and VOSL)
Social capital	▒	▒	▒	▒
Flows				
Outputs				
Agricultural and food production	▒	▒	▒	▒
Income / operating surplus	▒	▒	▒	Consumer costs
Purchased inputs to production	▒	▒	▒	▒
Labour	▒	▒	▒	▒
Intermediate inputs (fuel, fertilizer, etc.)	▒	▒	▒	▒
Ecosystem services				
Provisioning	▒	▒	▒	▒
Regulating	Environmental costs	▒	▒	▒
Cultural	▒	▒	▒	Different income-groups separated
Residual flows				
Food waste	▒	▒	▒	▒
Pollution and emissions (excess N & P, GHG emissions, etc.)	▒	▒	▒	Value of carbon

🟩	Descriptive information available
🟧	Quantitative information available
🟦	Monetized information available
▒	Not included in study

Policy questions that a TEEBAgriFood Framework-testing study can inform

This study provides policy makers with a framework for analysing the societal impacts of relatively small changes in dietary patterns, on economic, health and environmental dimensions. It could equally be used to ask:

- What would be the impacts of larger changes (greater than 5 per cent) on these dimensions? Is the existing model able to reliably estimate the impact of such (larger) changes?
- While the study finds that taxes on health-based restrictions are not likely to be cost-effective, it also finds that the values of health benefits induced by dietary recommendations are often much greater than those of environmental benefits; if taxes are not effective, what alternative policy measures could capture and attribute the costs of different diet choices?

Lessons learned

The comparison of diets as presented in the study provides a methodology for assigning the costs and benefits of different impacts jointly. Information from different scientific disciplines is required, even as different effect models must be used and many assumptions have to be made. By using monetary valuation estimates, the value of the different effects can be assessed jointly. From a societal perspective, the joint analysis is preferable. What is interesting for TEEBAgriFood as well is that the values of health benefits induced by dietary recommendations are often much greater than environmental benefits (except in the case of a very high CO_2 price).

8.3.3.2 CASE STUDY 6: Ten diet scenarios and carrying capacity of agricultural land in US

This study analyses impacts of dietary change on land use and carrying capacity by exploring 10 different diet scenarios (Peters *et al*. 2016). It uses a "Foodprint model" to estimate land requirements for 10 distinct diet scenarios:

- BAS (baseline)
- POS (positive control, intake of fats and sweeteners is reduced to make diet energy-balanced.)
- OMNI 100 (100 per cent healthy omnivorous)
- OMNI 80 (80 per cent healthy omnivorous)
- OMNI 60 (60 per cent healthy omnivorous)
- OMNI 40 (40 per cent healthy omnivorous)
- OMNI 20 (20 per cent healthy omnivorous)
- OVO (ovolacto vegetarian)
- LAC (lacto vegetarian)
- VEG (vegan)].

The reference diet (BAS) reflects contemporary food consumption patterns based on loss-adjusted food availability data from 2006–2008 (USDA Economic Research Service 2010). The concept of a "foodprint" is an analytical device related to assessing the capacity of a "foodshed", defined as the geographic location that produces the food for a particular population.

The scenarios in this study used biophysical models pertaining to land use change explored how assumptions about the suitability of cropland for cultivated crops influences estimates of carrying capacity. The baseline scenario had the highest total land use requirement, 1.08 ha person^{-1} year^{-1}, followed closely by the positive control, 1.03 ha person^{-1} year^{-1}. Land requirements decreased steadily across the five healthy omnivorous diets, from 0.93 to 0.25 ha person^{-1} year^{-1}, and the total land requirements for the three vegetarian diets were all similarly low, 0.13 to 0.14 ha person^{-1} year^{-1}.

All dietary changes increased estimated carrying capacity relative to the baseline. Diet composition greatly influences overall land footprint.

Table 8.10 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. Agricultural output is quantified with other provisioning and regulating services. The impacts of change in diets on human capital (through health) are described as an outcome.

Table 8.10 Case study 6 (diets in US): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production	Manufacturing and processing	Distribution, marketing and retail	Household consumption
Outcomes (change in capital)				
Natural capital				
Produced capital				
Human capital				Nutritional security
Social capital				
Flows				
Outputs				
Agricultural and food production	Crop yields Livestock production	Energy Food wastage		Food products (vegetarian and meat based) Food wastage
Income / operating surplus				
Purchased inputs to production				
Labour				
Intermediate inputs (fuel, fertilizer, etc.)				
Ecosystem services				
Provisioning	Biomass			
Regulating	High impact on natural resources in grazing land, low impact in cropland			High food print in grazing land, low impacts in cropland
Cultural				
Residual flows				
Food waste				
Pollution and emissions (excess N & P, GHG emissions, etc.)	High GHG emissions in grazing land, Low GHG emissions in cropland			

🟩	Descriptive information available
🟧	Quantitative information available
🟦	Monetized information available
⬜	Not included in study

Policy questions that a TEEBAgriFood Framework-testing study can inform:

The scenarios focused solely on differences in food consumption patterns and resulting impacts on land use requirements, and thus the study lends itself to a specific set of policy questions such as:

- Given a limited, set amount of crop acreage and grazing land within a country, what dietary changes that can help attain different levels of food security?
- To what extent is each food commodity land requirement dependent on ecosystem services, and/or on external inputs? What are the relevant positive and negative externalities of the contrasting diets and associated food production systems?

- The concept of "foodsheds" is intended to describe a region where food flows from the area that it is produced to the place where it is consumed, including the land it grows on, the route it travels, the markets it passes through, and the tables it ends up on. Can such an analysis of "foodprints" contribute to understand 'foodsheds', and the theoretical land use requirements for building local food systems (thus also incorporating metrics on the positive and negative externalities of processing and distribution for local communities)?

Lessons learned

This case study provides per capita land requirements and potential carrying capacity of the land base of the continental U.S. under a diverse set of dietary scenarios. It provides a good example for the application to the consumption side of the TEEBAgriFood Framework. This study focused on land requirements for different types of diets and hence associated greenhouse gas emissions and food wastage. Such studies could also utilize economic valuation methods to examine the associated changes in the value of natural capital. Therefore, the TEEBAgriFood Framework can assist in addressing these issues, and help to inform policy.

8.3.4 Policy evaluation

Two examples are presented in this section: i) a pesticide tax in Thailand, and ii) the Sloping Land Conversion Program in China.

8.3.4.1 CASE STUDY 7: Pesticide tax in Thailand

Until the late 1990s policies in Thailand supported the use of pesticides, as in other lower income countries in East and Southeast Asia, in order to stimulate agricultural production. Subsidized farm credit programs and other causes led to the greater use of pesticides (Praneetvatakul *et al.* 2013). Over the period from 1987 to 2010 agricultural pesticide use in Thailand increased from 1 kg/ha to 6 kg/ha, on average, while the pesticide productivity (gross output per unit of pesticide use) decreased from 400 USD/kg to 100 USD/kg. Besides the negative effect of pesticides on the environment, the health of farmers, farm workers and consumers is also exposed to risks.

A study was undertaken by Praneetvatakul (2013) to provide a quantitative analysis of the external costs of pesticides, to help policy makers understand who was bearing these costs, and where policy might intervene to reduce or eliminate these. Two approaches were used.

In one approach, a set of base values for eight external costs (related to farm worker health, consumer health, and the environment) associated with the application of one kg of active pesticide ingredients was calculated, using the Pesticide Environmental Accounting (PEA) methodology (see partial equilibrium model in Chapter 7) developed by Leach and Mumford (2008). This analysis showed that by far the highest cost of pesticide externalities falls on farmer workers and their health (83 per cent) while health costs to consumers are estimated at 11%.

The second approach used data on government spending related to pesticide use, which was collected from government agencies as per Jungbluth (1996), to estimate the actual cost of pesticide use, looking specific policy measures such government budgets for pest outbreaks, pesticide research and enforcement of food safety standards.

Between these two analyses, the priority revealed by government spending shows that greater importance is placed on food safety, while considerably less resources are allocated to the protection of farm worker health. The impacts of a pesticide tax were considered but research from various countries shows that the demand for agricultural pesticides is typically inelastic and that a tax would have a weak effect on demand, though it would generate considerable government revenues (Falconer and Hodge 2000). The study authors estimate that an environmental tax would raise pesticide prices by 11-32 per cent, yet would be insufficient to address the problem (see Dose Response Function method in chapter 7). Since the greatest costs are currently being incurred on the farm by pesticide appliers and pickers, it can be questioned if a pesticide tax will actually address these costs unless it is explicitly formulated to do so. To best target where interventions are needed, the study recommends the introduction of measures supporting non-chemical pest management methods, focusing on on-farm practices, such as Integrated Pest Management (IPM) methods, Farmer Field School (FFS), farmer training and education.

Table 8.11 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework, demonstrating how policy makers might use such studies to make external costs visible, and thus help to define economic policies (e.g. taxes or incentives) for pesticide use. To be effective, policies and social institutions must address areas of greatest costs and benefits along the food system; the TEEBAgriFood Framework has utility in identifying these areas. This study included the food value chain from impacts of production methods to impacts on consumer health. It referred to ways that ecosystem services (non-chemical pest control) could mitigate costs on the environment, and human health.

Table 8.11 Case study 7 (pesticide tax): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production	Manufacturing and processing	Distribution, marketing and retail	Household consumption
Outcomes (change in capital)				
Natural capital	⬜	⬜	⬜	⬜
Produced capital	⬜	⬜	⬜	⬜
Human capital	🟧 Farm worker health impact by applying pesticides, Farm worker health impact – effects from picking, Health costs due to acute pesticide poisoning, Costs related to BPH outbreak in 2010	⬜	⬜	🟧 Consumer health – groundwater, Pesticide contamination of fruit and vegetables
Social capital	⬜	⬜	⬜	⬜
Flows				
Outputs				
Agricultural and food production	🟦 Gross output	⬜	⬜	⬜
Income / operating surplus	⬜	⬜	⬜	⬜
Purchased inputs to production	⬜	⬜	⬜	⬜
Labour	⬜	⬜	⬜	⬜
Intermediate inputs (fuel, fertilizer, etc.)	⬜	⬜	⬜	⬜
Ecosystem services				
Provisioning	⬜	⬜	⬜	⬜
Regulating	🟩 Habitat for biodiversity, Beneficial insects for pest control	⬜	⬜	⬜
Cultural	⬜	⬜	⬜	⬜
Residual flows				
Food waste	⬜	⬜	⬜	⬜
Pollution and emissions (excess N & P, GHG emissions, etc.)	🟩 Pesticide impact on aquatic life, birds, bees, insects	⬜	⬜	⬜

🟩	Descriptive information available
🟧	Quantitative information available
🟦	Monetized information available
⬜	Not included in study

Policy questions that a TEEBAgriFood Framework-testing study can inform

This study provides an opportunity for policy makers to assess the following:
Can the results aid policy makers in determining where interventions will provide the most benefits? If clear negative externalities can be quantified (as they have been in this study), yet experience in other countries indicate that a pesticide tax may not be sufficient to change outcomes, what other measures might accompany or replace tax measures?
What would be the outcomes of incorporating impacts and benefits generated by ecosystem services in alternative pest management strategies? For example, what would be the impacts on pesticide policy if health impacts on farm workers were considered? Could consideration of the additional benefits possible for incorporating aquaculture in rice production systems (where pesticides are minimized or eliminated) change the equation between benefits and costs, and for whom?

Lessons learned

This case study suggests that there is a need for a change from an institutional framework that promotes pesticides to one that takes into account the risks and is adjusted to the true costs and benefits of their use. The TEEBAgriFood Framework takes these costs and benefits into account, showing the external costs of pesticide use on consumers' health, farmers' health and the environment on a country level. It appeared that the majority of the external costs of pesticide use accrue to farmworkers and not to consumers, yet the study is one of the few that records impacts across the food value chain. In addition, the results show that an environmental tax would raise pesticide prices by 11-32 per cent. Considering these results, the TEEBAgriFood Framework has the potential to show which stages in the value chain or which (visible or invisible) flows are most affected by the use of pesticides. The Framework can thereby help direct policy. Since analysis shows that the greatest costs are currently being incurred on the farm, amongst pesticide appliers and pickers, it can be questioned if a pesticide tax will actually address these costs. The study noted that pesticide demand is fairly inelastic and is not likely to decrease because of the tax. It is also unlikely that the tax will be applied in a manner that addresses farmworker health (or provides funding research for production methods that use less pesticides) unless it is explicitly formulated to do so. In order to reveal this potential, the relative impact of pesticide use in the different stages of value chains or between (visible or invisible) flows need to be made clear within the Framework, in order to provide policy guidance on where interventions should be developed.

8.3.4.2 CASE STUDY 8: The China Ecosystem Assessment: Sloping Land Conversion Program

The study showcased here reports on the results of the first Chinese Ecosystem Assessment (CEA), which covered all of mainland China from 2000 to 2010 (Ouyang *et al.* 2016). The CEA is the first assessment of various ecosystems and ecosystem services since the Sloping Land Conversion Program (SLCP) was started to stop deforestation and erosion that led to severe flooding along the Yangtze River in 1990s. Bio-physical assessment models such as hydrological models and the Integrated Valuation of Environmental Services and Trade Offs (InVEST) were used in the study to assess ecosystem services. All ecosystem services evaluated increased between 2000 and 2010, with the exception of habitat provision for biodiversity. Food production had the largest increase (38.5 per cent), followed by carbon sequestration (23.4 per cent), soil retention (12.9 per cent), flood mitigation (12.7 per cent), sandstorm prevention (6.1 per cent), and water retention (3.6 per cent), whereas habitat provision decreased slightly (–3.1 per cent).

Table 8.12 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. Various outputs in the form of agricultural products are quantified along with all ecosystem services (carbon sequestration, beneficial insects, soil retention etc.). The impacts on natural capital (changes in soil and water quality through soil and water retention) are also quantified in the study.

Table 8.12 Case study 8 (Chinese Ecosystem Assessment): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production	Manufacturing and processing	Distribution, marketing and retail	Household consumption
Outcomes (change in capital)				
Natural capital	Land degradation, water pollution			
Produced capital				
Human capital				
Social capital				
Flows				
Outputs				
Agricultural and food production	Food production, timber			
Income / operating surplus	Output surplus			
Purchased inputs to production				
Labour	Wages and Profits in watershed ecosystems conservation, Land rent			
Intermediate inputs (fuel, fertilizer, etc.)	Fertilizer/pesticides inputs			
Ecosystem services				
Provisioning	Food, timber			
Regulating	Carbon sequestration, soil retention, sandstorm prevention, water retention, flood mitigation, Biodiversity conservation Habitat for biodiversity			
Cultural	Agricultural heritage			
Residual flows				
Food waste				
Pollution and emissions (excess N & P, GHG emissions, etc.)	GHG emissions, surface runoff, leaching of chemicals			

🟩	Descriptive information available
🟨	Quantitative information available
🟦	Monetized information available
⬜	Not included in study

Policy questions that a TEEBAgriFood Framework-testing study can inform

An important component of any food system transition will be the relative expansion and contraction of labour demands. This case study included in its focus, along with a number of ecosystem services, the wages and profits in watershed ecosystem conservation. The program has reduced poverty in the Yellow River basin by increasing the income of participating households through the compensation payment and shifting the labour force from farm activities to non-farm work. The study is also distinctive in being relatively long term, over ten years, and providing a contrast in the sense of "before" and "after" government intervention. Relevant questions include:

- Looking into the future, can the expansion in wages and labour be sustained?
- Will this require continued government interventions and subsidies?
- How can the value created through restoration of ecosystem services be applied to sustaining conservation and restoration activities over time?
- What are the linkages between protection of ecosystems, livelihoods and public health?

Lessons learned

Results from The Natural Forest Conservation Program (NFCP) and the Sloping Land Conversion Program (SLCP) are unique, thanks to the studies' size and longevity. The SLCP presents the results from a truly massive investment of more than US$50 billion, directly involving more than 120 million farmers in 32 million households. The Programs focused solely on production systems, but considered a wide range of ecosystem services that have large impacts on the landscape level of the production system (sandstorm protection, water retention, flood mitigation, etc.). It is interesting however that the study itself, while finding many positive benefits from the "payments for ecosystem services" schemes, nonetheless finds that many environmental challenges remain, including issues with water quality. This suggests several possibilities: that the interventions are not sufficiently targeting root causes, or that the incentive systems are not enough to overcome existing disincentives leading to environmental pollution. To inform policy, applying the TEEBAgriFood Framework could assist in addressing these policy questions, if the challenges are included in the scope of the study.

8.3.5 National accounts

Two examples are presented in this section: i) agriculture development in Senegal, and ii) Australian Environmental Economic Accounts in agriculture.

8.3.5.1 CASE STUDY 9: Agriculture development in Senegal

This study aims to provide analysis of the socio-economic and environmental impacts of the agriculture development through provision of World Bank's loan for 'sustainable and inclusive agribusiness development project' during 2014-2020 to the Government of Senegal (Millennium Institute 2015). The study examines scenarios for social, economic and environmental development based on alternative investment in small-scale ecological and knowledge-intensive approaches, as opposed to high external-input, agricultural systems, at a national level. The Millennium Institute used its Threshold-21 (T21) simulation model (system dynamics model)– an integrated and dynamic planning tool – that enables transparent cross-sectoral analyses of the impacts of policies, and enables exploration of their direct and indirect long-term consequences on social, economic and environmental development (Pedercini 2010).

Four scenarios are analysed in this study: the Base Run scenario (without the World Bank loan), the World Bank loan scenario (in which the World Bank loan is implemented as suggested, mainly focusing on investment in irrigation infrastructure), and two alternative scenarios in which the World Bank loan is implemented but its focus is changed towards the support of small producers and farmer training. In the base run scenario, crop production accounted on average for around 60 per cent of total agriculture GDP between 1980 and 1990, decreased to around 55 per cent between 2005 and 2015 and declines to less than 45 per cent between 2040 and 2050. In the same periods, value added from livestock increases from around 23 per cent to around 30 per cent to 44 per cent. Average life expectancy increases from less than 50 years in 1980 to around 60 years around 2010 and nearly 90 years at the end of the simulation in 2050. Water demand increases for most of the simulation period and stabilizes shortly after 2045.

In the World Bank loan scenario, crop value added is around 7 per cent higher than the base scenario. For the social indicators in 2050, agriculture employment is 27 per cent greater in the World Bank loan scenario than in the Base Run. The water stress index, the ratio between water demand and available water, in 2020 is 40 per cent higher in the scenarios in which the World Bank loan is mainly invested into irrigation infrastructure, since this increases the agricultural water demand. However, in 2050 there is no difference in water demand compared to the Base Run, since at this point irrigation infrastructure is the same in all four scenarios because the limit of 350,000 ha, maximum area that can be equipped with irrigation infrastructure, has been reached.

Table 8.13 indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. It covers all aspects of the value chain and provides information on agriculture output and regulating services. It also provides estimate of impacts on natural capital especially water and land.

Table 8.13 Case study 9 (Senegal loans): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production	Manufacturing and processing	Distribution, marketing and retail	Household consumption
Outcomes (change in capital)				
Natural capital	🟧 Impact on land and water	⬜	⬜	⬜
Produced capital	⬜	⬜	⬜	⬜
Human capital	⬜	⬜	⬜	🟩 Nutrition Health Life expectancy
Social capital	⬜	⬜	⬜	🟩 Food security and Education
Flows				
Outputs				
Agricultural and food production	🟦 Food	⬜	⬜	⬜
Income / operating surplus	🟦 Profits Taxes	🟦 Profits Taxes	🟦 Profits Taxes	🟦 Profits Taxes
Purchased inputs to production				
Labour	🟦 Wages	🟦 Wages	🟦 Wages	🟦 Wages
Intermediate inputs (fuel, fertilizer, etc.)	🟦 Irrigation Subsidies, Fertiliser use, pesticide use, seed etc.	⬜	⬜	⬜
Ecosystem services				
Provisioning	🟦 Water Energy	🟦 Water Energy	🟦 Water Energy	🟦 Water Energy
Regulating	🟧 Water Soil fertility Organic matter	⬜	⬜	⬜
Cultural	⬜	⬜	⬜	⬜
Residual flows				
Food waste	⬜	⬜	⬜	⬜
Pollution and emissions (excess N & P, GHG emissions, etc.)	🟦 GHG emissions	🟦 GHG emissions	🟦 GHG emissions	🟦 GHG emissions

🟩 Descriptive information available

🟧 Quantitative information available

🟦 Monetized information available

⬜ Not included in study

Policy questions that a TEEBAgriFood Framework-testing study can inform

The different scenarios presented suggest an interesting way to present decision trade-offs to policy-makers in a TEEB like analysis. The Threshold-21 (T21) simulation model applies economic valuation (direct market price) to many aspects in previous case studies that lack monetary values including water provisioning, food security, education, and GHG emissions. The application of the TEEB Framework to this study thus provides a tool that can aid policy makers in analyzing monetary investments, such as bilateral or multilateral loans.

- How does investing in inputs and infrastructure compare to investing in small scale producers and training, in terms of impacts on non-market ecosystem services?
- Can ecosystem services be monetized so that a common metric can permit more concrete analysis? Or would other quantitative or qualitative metrics be more suitable?
- Can the model be revised to more explicitly distinguish additional positive externalities, along with the evident negative ones such as GHG emissions? Education is considered; but further social variables such as social cohesion and cultural traditions of smallholder farming could also be considered (despite the challenge in terms of monetization).
- This analysis considered only a relatively small loan and its impact. What would be the outcome of applying the analysis at a larger scale, perhaps at the level of a national budget?

Lessons learned

This case study provided coverage across the food value chain and the impacts on National Accounts, while taking into account different ecosystem services, health impacts and social values. In this sense, it is one of the most complete studies to which to apply the TEEBAgriFood Framework. By including a comprehensive set of sectors and factors, the analysis can make many linkages that are hard to predict in more linear studies; for example, it demonstrates the positive impact of investing in training of smallholder producers rather than investing primarily in infrastructure when looking at social indicators such as employment, poverty reduction and food security. Based on a systems dynamics model, its greatest value is in a dynamic comparison of four competing models for policy makers.

8.3.5.2 CASE STUDY 10: Australian Environmental-Economic Accounts for agriculture

The Australian Bureau of Statistics (ABS) produces a set of environmental-economic accounts (Australian Bureau of Statistics 2017) each year measuring environmental assets (land, soil, timber, water resources), which increased 95 per cent over the period 2005-06 to 2014-15 from $2,999.5 billion to $5,837.5 billion. The value of Australia's produced capital also increased over this period, although to a lesser extent (70 per cent), rising from $3,276.7 billion to $5,564.1 billion. Environmental assets now make up the largest share of Australia's capital base, mainly in the form of land (83 per cent) and mineral and energy resources. Australian Environmental-Economic Accounts (AEEA) follow the System of Environmental-Economic Accounting 2012—Central Framework (SEEA Central Framework) for the evaluation of these assets. This multipurpose conceptual framework describes the interactions between the economy and the environment, and the status and changes in stocks of environmental assets (UN 2014). The SEEA Central Framework applies the accounting concepts, structures, rules and principles of the System of National Accounts (SNA), which uses Computable General Equilibrium (CGE) models that includes supply and demand across all sectors in an economy.

Here the environmental-economic accounts (Australian Bureau of Statistics 2017) related with agriculture sector and reflected in national accounts of Australia are summarised in **Table 8.14**, which indicates the coverage of this case study in accordance with the TEEBAgriFood Evaluation Framework. This study covered all aspects of the value chain and provided monetary estimates of changes in natural and physical capital associated with the agriculture sector in Australia. However, it did not provide any estimate of waste generated through the value chain or cultural services in agriculture.

Table 8.14 Case study 10 (Australia environmental-economic accounts): a checklist for scoping which elements of the TEEBAgriFood Evaluation Framework are assessed

Value chain	Agricultural production	Manufacturing and processing	Distribution, marketing and retail	Household consumption
Outcomes (change in capital)				
Natural capital	Land appreciation/ degradation			
Produced capital				
Human capital				Nutrition Health Life expectancy
Social capital				
Flows				
Outputs				
Agricultural and food production	Crops	Food	Food	Food
Income / operating surplus	Wages	Profits	Profits	Wages/profits
Purchased inputs to production				
Labour	Wages	Wages	Wages	Wages,
Intermediate inputs (fuel, fertilizer, etc.)	Irrigation Subsidies, Fertiliser use, pesticide use, seed			
Ecosystem services				
Provisioning	Water, Energy	Water, Energy	Water, Energy	Water, Energy
Regulating	Water, Soil fertility, Soil carbon	Water, Soil fertility, Soil carbon	Water, Soil fertility, Soil carbon	Water, Soil fertility, Soil carbon
Cultural				
Residual flows				
Food waste				
Pollution and emissions (excess N & P, GHG emissions, etc.)	GHG emissions	GHG emissions	GHG emissions	GHG emissions

🟩 Descriptive information available

🟧 Quantitative information available

🟦 Monetized information available

⬜ Not included in study

Policy questions that a TEEBAgriFood Framework-testing study can inform

This case study explores the importance of application of the Framework at macro level to capture value of natural capital in the national accounts. It can help address following policy questions.

- How can a national-level TEEBAgriFood analysis best be integrated into national accounts for natural capital or environmental assets? What kinds of policy guidance might this provide to decision makers?
- Alternatively, can a TEEBAgriFood analysis be carried out as an annual national statistical exercise, helping citizens to understand trends over time with ecological restoration activities as per the China Ecosystem Assessment case study?

Lessons learned

The case study of the Australian Environmental-Economic Accounts for Agriculture provides a very useful link to the concept of “stocks” or “natural assets” which the TEEBAgriFood Framework could profitably build upon. However, there is an underlying concept in these accounts that uses metrics reflecting concepts such as energy or water intensity to reflect the amount of resources used per unit of economic output. This same concept arises in the case study on grain-fed versus grass fed beef, above, in which one study argues that pasture fed beef from managed grazing systems is more “greenhouse gas intensive” per kg of meat produced than feedlot finished. Nevertheless, we note that this calculation, and the calculations in the Australian national accounts, are made on a per unit of product basis. Industrial agriculture will always perform better than more agro-ecological approaches when emissions are expressed on per kg of produce, given the higher levels of productivity of the former in the global scheme of agricultural production. Yet what causes global warming is the total net emission of greenhouse gases per area, regardless of yields. Thus, we would caution against solely using metrics reflecting efficiency, and urge that metrics always consider the totality of negative (and positive) externalities and their impacts.

8.4 SOCIAL INEQUITIES

The impacts of eco-agricultural systems are not homogenous across an entire society, and depend on factors including gender, culture and income. Building on chapter 5’s look at equitable food systems and drivers for change, we have elaborated on inequities concerning social impacts that can occur at various stages in the value chain (production, processing and distribution, and consumption). Here, we draw attention to how impacts affect societal groups differently, and how this should be reflected in applications of the TEEBAgriFood framework.

1. Production

Equity requires that no social groups fall below minimum standards of environmental health, e.g., water quality for all communities should not fall below the standards. Chapter 4 gives an overview of occupational health hazards of agriculture. These health effects are variable depending on exposure rates as well as individual sensitivity. Health hazards are also affected by type of farming activity, type of worker, geographic location, inequities in health service and other social inequalities (such as wealth, education, and training). Chemical exposure and protection of farm workers also varies widely between developing and developed countries. Data from the 1990s show that developing countries account for 20 percent of all pesticide use, while more than 99 percent of human poisoning related to pesticides took place in developing countries (Cole 2006). This is highlighted in case study 7 on pesticide taxes in Thailand, where (1) externalities of pesticide use on farmworkers is ten-fold that of consumers, and (2) pesticide use has increased six-fold from 1987 to 2010 (a trend much more pronounced in developing countries).

Greenhouse gas (GHG) emissions, as potent contributors to climate change, are included as part of the TEEBAgriFood Framework and differences in emissions levels are among the indicators noted in the rice and beef studies explored in above sections. Agriculture’s contribution to GHG emissions and climate change is increasingly acknowledged. As noted here, the production of animal protein and rice are both known to potentially emit high levels of greenhouse gases; levels that can be in some measure mitigated by adopting specific practices or production systems. However, in other respects, the sheer quantity of consumption of product such as meat- with a long “greenhouse gas” shadow suggests that the most important mitigation measure is further along the food value chain, in rebalancing diets and reducing the per capita consumption of meat in developed countries. In terms of social equity, the costs of climate change fall heavily on small-scale farmers and fishers in developing countries, both in terms of impacts and capacity to adapt to those impacts.

2. Processing and distribution

The processing and distribution phase of food systems impact society unequally, both in developed and developing countries. Many farmers are unable to make a living out of farm income alone, which affects family needs such as health care and social security. Access to income generating opportunities in the processing and distribution aspects of food systems is often critical for household incomes. However, as noted for example in the Grass-fed versus Grain-fed beef case study, processing facilities such as large-scale beef feedlots are often located in low-income neighbourhoods. This can provide much needed employment but also generate significant air and water pollution. Similarly, the social value of access to affordable food for all consists of several inequities such as trends in undernourishment and access to food between and within countries. For instance, poverty rates are often higher in rural areas than urban areas while the urban poor may be more sensitive to (changes in) food prices.

3. **Consumption**

In chapter 4 the variability of social impacts related to food consumption is explored. The link between food access, food security and nutrition is discussed (e.g. access to food from supermarkets vs informal markets). Changes in diets are also considered in two case studies in this chapter; however, having convenient access to a variety of diet options is often a luxury associated with relatively high incomes; food "deserts" where mostly processed food is available is the reality in many low-income areas. The resulting issues of food access and malnutrition can severely affect children and the more vulnerable.

8.5 CHALLENGES AND LIMITATIONS

In this chapter, we showcased 10 applications of the TEEBAgriFood Evaluation Framework to the existing set of case studies in an exploratory way. In doing so we have identified some challenges in each of the five families of applications.

There are not many known examples where the Framework is applied comprehensively. Therefore, we have only been able to demonstrate limited aspects of the Framework and have commented on its use to inform practice and policy accordingly. Agricultural production is not studied comprehensively across how food products are processed, distributed or used. The primary focus has long been on increasing productivity. This leads to partial assessment of sustainability. A comprehensive framework can help resolve these issues. Similarly, for the analysis of products, diets, policy and national accounts, there is little emphasis on the entire value chain. Therefore, research must be reprioritized to help better plan for future analysis that considers the entire value chain in order to evaluate all stocks of capital (natural, social, human) and flows (of ecosystem services and other inputs or outputs) in the agriculture sector. The case studies also reveal several 'gaps' in the Framework (i.e. unfilled boxes in showcased examples) that require future research.

Data gaps exist for each of the examples highlighted in the chapter not only because of the need for more research but also because the case studies were not designed to reflect flows of ecosystem services and different capitals through the entire value chain. For example, under agricultural management systems, selected studies focused on identified ecosystem services and not on natural, social or human capital. Products (palm oil and beef) highlighted in the chapter also have some focus on impacts on consumer's health and animal health but not all aspects are covered. In the two examples related to policy evaluations, there is need to collect data on the impact on different capitals and ecosystem services and to explore alternatives.

At this stage in the development of the TEEB Framework and our understanding of the literature, there is no single study that provides a complete picture of how the Evaluation Framework can be applied comprehensively. However, the examples included provide sufficient evidence that a comprehensive study through the entire value chain can enhance potential development of sustainable agricultural and food systems. This information then can be used to inform policy for appropriate response at local, national and global level. From the case studies presented in this chapter, and by way of example, the potential utility of the framework to policymaking has been indicated in the following instances:

Agricultural management systems: Policy makers can employ the TEEBAgriFood Framework to understand the extent to which a specific production system (such as organic farming) minimizes negative externalities on water resources, while generating sufficient yields and other benefits, and how this might be supported through greater farmer training.

Agricultural product: Policy makers can employ the TEEBAgriFood Framework to evaluate the value, throughout the food chain (thus for producers, but also communities living near processing plants, and consumers) of alternative, low-impact ways of creating agricultural products.

Dietary comparison: A TEEBAgriFood analysis permits policy makers to consider issues of environmental sustainability of diets, along with nutrition and social equity. For instance, some studies suggest that having a component of grass-fed meat in a diet can be more sustainable, in environmental terms, than a purely vegetarian diet (Peters *et al.* 2016)

Policy evaluation: One way of "costing" negative externalities may be through taxes, such as a pesticide tax, or a soda tax. Generally, these are formulated to address one issue: pollution, or obesity for example. A TEEBAgriFood assessment permits policymakers to understand where, along the food value chain, multiple costs as well as benefits are occurring. Thus, policy makers can better understand where measures to address costs might be applied, in a more holistic manner, to provide incentives for transitions to systems with benefits in multiple dimensions.

National accounts: There are increasing efforts to bring natural capital accounting into the national agriculture and food sector in order to assess multiple forms of capital beyond simple measures of yield and productivity.

Realizing these potential uses, however, will require considerable effort and time, which has not been fully estimated. However, there is need to consider resources and capacity development while suggesting the application of the TEEBAgriFood Evaluation Framework.

Limitations

In addition to the above data gaps and research priority challenges, there are several limitations for populating the Framework, which are mentioned below.

- There is need to understand risks and uncertainties in the application of the Framework to agribusiness, government sector, consumers and research. The Framework in its current form provided as a universal tool, which can be applied in various situations. It is expected that with each application, the Framework will be modified to manage risks associated with degradation of natural, social and human capitals.

- There is need for policies to adopt the framework at micro (e.g., farm level) or macro (e.g., landscape or regional) level. It is expected that comprehensive applications of the framework will help trigger the right policy response.

8.6 CONCLUSIONS

The examples highlighted in each of the five families of application demonstrate various aspects of the eco-agri-food value chain along with its positive and negative externalities. It can be concluded that the Framework has potential to be a useful tool to develop appropriate policy response by exploring the entire agriculture and food value chain and recognising, demonstrating and capturing the value of all ecosystem services in eco-agri-food systems. An initial exploration through existing case studies helps showcase various challenges and limitations of the Framework, and provides insights about modifications and adaptation that will be required to fully realize the potential usefulness of the Framework. The explorations within this chapter are an introduction to a process that will continue, as lessons are learned with each application of the Framework. Through applying the Framework and bringing the results into policy making arenas, it will be possible to identify and address the significant externalities that distort the current economic system around agriculture and food. Such an analysis can be the essential groundwork for applying a Theory of Change, as elaborated in Chapter 9 to follow.

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CHAPTER 9

THE TEEBAGRIFOOD THEORY OF CHANGE: FROM INFORMATION TO ACTION

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SUMMARY

Chapter 9 shows how adopting the TEEBAgriFood Evaluation Framework can bridge the gap between knowledge and action. Factors that block the absorption of externalities in food systems, including path dependency and counter-narratives regarding healthy diets, lead us to derive lessons for transformational change reflecting the critical role of power relations. Experience in agri-food certification and multi-stakeholder roundtables bespeak the need to address change from the starting point of key actors and relevant groups, including farmers, government, industry and consumers. Successful change in food systems to reflect invisible values can be enabled by identifying specific action roles through partnerships and alliances as well as multilateral agreements including the SDGs.

CONTENTS

FIGURES, TABLES AND BOXES

CHAPTER 9

9.0 KEY MESSAGES

- Information alone often fails to motivate change. Manipulation of data has led consumers to doubt scientific results, serving special interests at the expense of public benefit. Information overload implies the need for synthesis to enable better access and impact.
- Rationalizations against the need for change include: fatalism, arguing that business is already changing of its own accord, that cheap food is more important than good food, and that the marketplace will adjust for externalities.
- These views do not address the long-term systemic consequences of the global corporate model of food systems in a society that derives calories from corn syrup and protein from hamburger resulting in obesity and disease.
- Free market, neoliberal policies are incapable of resolving externalities that affect public goods such as ecosystem services. Faith in the infallibility of the market is a shortcoming of economics.
- Path dependency is a key barrier to change in food systems, causing inertia, but may also lock-in positive systemic change. A science of intentional systemic change is arising, grounded in better understanding of human economic behavior as the basis for collective action.
- We espouse not one theory but rather a range of actor-relevant theories of change.
- Consumer advocacy can bring businesses to assume greater responsibility for the effects of their actions. This theory of change has found expression in the threat of boycotts and reputational risk.
- Certification has led to improvement in production practice within market niches but its true success begins when it pressures change in policy and practice throughout supply chains.
- Governance of intentional transformation in food systems requires knowledge of political pressure points, and systematic efforts to shape narratives of principal actors, to redirect financial resources and to promote institutional and societal learning and adaptation.
- We address the potential of multilateral organizations and agreements, national governments, the financial industry, agribusiness, producers and consumer groups to respond to the need for change. The roles of different actors are interlocking: there is no single point of entry for a theory of change.
- The roles of principal actors are drawn along a continuum of change, suggesting specific roles and types of actions to be addressed in evaluation and intervention. Given societal concern, agents for change may persevere within government, agribusiness or civil society organizations; their ability to bring change is dynamic and opportunistic, and driven by strategic alliances. As levers of agrifood system transformation, it is crucial to engage influential governmental actors as change agents.
- Actors’ respective ability to adopt the results of TEEBAgriFood studies as a tool to direct change will depend on how well those results are communicated and adopted as narratives by influential actors and as entry points for education and consumer consciousness.

CHAPTER 9

THE TEEBAGRIFOOD THEORY OF CHANGE: FROM INFORMATION TO ACTION

9.1 INTRODUCTION – DEFINING A THEORY OF CHANGE IN RESPECT TO TEEBAGRIFOOD

This chapter shows how better knowledge on invisible costs provided to key actors in food systems can be used to influence decisions to escape from unsustainable path dependencies. This 'Theory of Change' serves as the backdrop to pathways to implementation in conjunction with global initiatives in Chapter 10.

A 'Theory of Change' (ToC) is defined as a basis for planning intervention in a given policy or project arena. Developing a ToC helps to identify processes whereby actions can best attain their intended consequences. The ToC approach also identifies preconditions deemed necessary to achieve desired goals. The TEEBAgriFood ToC responds to the expectation that knowledge and measurement of externalities, as assessed through valuation tools and the Framework included in this report, can be used to influence decision makers to redirect resources, products or practices so as to achieve greater sustainability in the food system. The relevant preconditions or points of entry to change in the food system include informed actors, compatible power relations, and favourable political economic conditions. The cornerstones of the ToC consist of supportive governance systems and enabling institutions as building blocks (including rules) and mindsets (both worldviews and values). Nevertheless, the specific combination of relevant entry points is context specific, corresponding to value chain conditions and a respective constellation of actors.

To give justice to these contextual variations, the chapter describes cases in which the TEEBAgriFood ToC may be played out. In these examples, the Evaluation Framework (see Chapter 6) is part of a "toolkit" that, in combination with countervailing public pressures and alliances, and instruments such as certification, incentives or sanctions, can be mobilized to address externalities in food chains. Since change generally implies that some stand to gain and others may lose when adopting different strategies or policies, the incidence of benefits and costs should be assessed (though a participatory approach can help assure buy-in from multiple parties from the outset).

The ToC must be sensitive to potential obstacles to change, while also suggesting ways to circumvent such obstacles, developing scenarios that consider human welfare, food security and environmental quality. While we recognize that "our ability to change our behavioural and cultural practices lags far behind our ability to manipulate the physical environment" (Wilson *et al.* 2014, p.395) the search for steps toward *intentional societal change* predominates in this discussion.

The TEEBAgriFood Framework offers a transparent and flexible approach to characterize externalities that arise in food systems. The TEEBAgriFood ToC suggests ways by which the Framework can adapt to actors' needs, limitations and strategies, in different social and strategic contexts. It provides a framework for evaluation and valuation opportunities available to key actors along food system value chains. As there is no single way forward, the chapter suggests different pathways and indeed distinct "theories of change" suitable for each of the initiatives described. A systems-wide perspective (as described in Chapter 2) is paramount, but the Framework is designed to be flexible in order that it may be tailored to a wide range of actors, including farmers, business people and consumers.

Figure 9.1 illustrates the functional domain of the TEEBAgriFood ToC within and among stakeholders to improve public knowledge and decision making processes and stimulate pressures for change. Other forces that drive and condition the political economic context, including institutions that mediate the prospects for change, including markets and property rights, are also essential building blocks in the ToC, but are beyond TEEB's immediate domain.

Figure 9.1 TEEBAgriFood Theory of Change functional domain (Source: authors)

In design

The purpose of this chapter, then, is to consider the potential to influence decision makers by making clear the interconnections between food systems and human wellbeing, and of their hitherto invisible externalities and social costs. The ToC is useful in showing pathways toward: 1) Mainstreaming TEEBAgriFood as an analytical basis, and in consequence, 2) Reforming food systems and restoring the ecosystems upon which they depend.

The chapter is structured as follows. First, we describe the recognition of the need for change in eco-agri-food systems by key actors, despite insufficient information. Use of the TEEBAgriFood Framework can also facilitate change through the dissemination of knowledge, and by appealing to peoples' growing concern with the origin and quality of the food they eat.

However, obstacles such as pushback, denial, lock-in and blockages are present in agri-food chains. In this light, the following section looks at conditions needed for successful transformational change in eco-agri-food systems. A strategy of transformative governance in eco-agri-food systems would require confronting existing power structures to press for financing to enact incentive systems necessary to motivate change. Promoting a sense of urgency is key; narratives focusing on rights, resilience and sustainability can convey a strong link between reforming the food system and improving health and quality of life.

In the following section, we show how positive pressures and strategic allies can influence principal actors in eco-agri-food systems. At the outset, we identify several counterfactual rationales that some actors (or narrower special interests) employ to push back against the pressing need for change in eco-agri-food system practices. Convincing these actors to buy in or pressuring them to concede the importance of invisible costs will greatly speed progress towards a more equitable and transparent food system.

We review several specific cases in which coalitions of actors have initiated change processes thanks to better information on externalities. Multi-stakeholder coalitions have promoted advances in certification and supply chain governance that influence broad market segments. Other processes in which additional information on food system externalities can make a crucial difference include: i) multilateral voluntary initiatives and science-policy interfaces (as a preamble to Chapter 10), ii) government decisions on incentives and sanctions at various levels, iii) due diligence procedures of the financial industry, iv) standard-setting and agribusiness coalitions, v) farm confederations promoting agroecological systems transitions at different scales and tenure arrangements, and vi) demands by consumer coalitions for food quality. Equity and health considerations are cross-cutting concerns across all such processes. For each process, we examine the chief drivers of change, including influential supporters and adversaries, as well as the roles of intermediary agents (extension workers, scientific researchers, epistemic communities, traders, supermarket chains, input suppliers, producer associations, social movements, etc.).

Enabling conditions must exist in order to allow successful transformation. Part of creating these conditions involves defining protocols and creating avenues to effectively and appropriately communicate results to different actor group. Policy decision-making and implementation contexts pose challenges but also opportunities for real progress towards a sustainable food future.

9.2 INFORMATION, AWARENESS AND COLLECTIVE ACTION ON PATH DEPENDENCY IN FOOD SYSTEMS

9.2.1 Information and denial: the politics of evidence

As other chapters have shown, the scale and intensity of externalities brought about by today's food systems have grown considerably in recent years, yet accounting for such externalities or mitigating their negative effects has not kept pace. Despite increased public scrutiny of the health and environmental effects of food and agricultural practices over the half-century since the publication of Silent Spring (Carson 1962), there remains considerable denial and pushback from the agribusiness and food supply industries as they manipulate consumer perceptions and deny the veracity of evidence supporting the need for change[1]. An informed public is a liability to some.

Relatedly, much of the information available regarding the eco-agri-food business is not always scientifically sound. Shepherd *et al.* (2013) and Rosenstock *et al.* (2017) reviewed 103 agricultural and environmental monitoring systems globally and found most lacked a clear conceptual framework or theory of change and were not designed with the statistical rigor necessary to ensure internal and external validity of results. Few provided a clear pathway for how the amassed data could enable actors to move from information to action. The need is not for "adequate information" but rather for more objective and concise information that responds to a clear and present need.

As a first step in defining TEEBAgriFood's Theory of Change, we posit that adequate information on the relevant costs of externalities associated with food production is either non-existent or has not been made readily available. It is also clear that providing such information in and of itself does not necessarily lead to action. Three possible reasons for this are:

1. Better information, at individual as well as organizational scale, does not easily translate into decision-making. This has been widely shown and discussed in psychology with respect to risk (e.g. health risks and tobacco) or more specifically with respect to environmental costs and risks (Weber and Johnson 2009). Rather, science-and-technology specialists insist on the primordial role of worldviews and political ideologies as leading factors influencing change. In this framework, information such as valuation and evaluation of the sustainability benefits and costs may have a positive effect only if it coincides with efforts to progressively shape visions and raise awareness that will trigger changes in value systems and in the collective deliberation process.

2. In a world of ever increasing information overload, much information is simply lost even to scientists and specialists in a given field. Doemeland and Trevino (2014) have shown, for example, that approximately one-third of the documentation made available by the World Bank is never downloaded. Although the amount of data made available speaks well for transparency, the usefulness of so much information can be called into question. This implies the need for improving the availability and access to systematic reviews and for producing evidence-retrieving and mapping instruments (McKinnon *et al.* 2015). It is also the case that information providers should not only offer what they think is needed, but respond to articulated needs. This also implies that information seekers know what they need in order to formulate good decisions. Valuations and evaluations will therefore increase their usefulness to their target audience if they are produced in a format that encourages their uptake by data systems, systematic reviews and meta-analyses. But first and foremost, they must provide information that is relevant to the questions users are facing. This is increasingly practiced in the field of environmental evaluation of policy instruments (for example, anti-deforestation policies) but should be developed as well for external agricultural costs and benefits.

3. Deliberate strategies and "strategic unknowns" (McGoey 2012; Rayner 2012) that are designed to cause confusion, defuse knowledge and generate ignorance, exist in many environmental fields such as climate change (Oreskes and Conway 2010) but also in the field of agriculture and the environment. Kleinman and Suryanarayanan (2012) have documented the case of honeybee decline and other

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[1] An emblematic case of the manipulation of public opinion and misrepresentation of science by industry is that regarding the urgency of action against climate change.

agrochemical damages, whereas Dedieu *et al.* (2015) describe the strategy behind the under-reporting of farm-workers pesticide poisoning in California and France. Elliott (2012) analyzes how agricultural research is oriented so as to select or block certain topics and sources, such as non-industry-funded works on GMOs. Stocking and Holstein (2009, p.25) analyze how journalists "magnify, downplay, emphasize or ignore attempts to manufacture doubts in a scientific controversy", for the case of nuisance caused by hog breeding industries on the environmental quality of nearby water bodies. This handful of examples suggests that the impact of information produced on the true costs and benefits of agriculture will not result solely from the message being diffused. Rather, it will have to overcome strategies from various groups whose interests are not aligned with these messages, and target those whose professional practice is receptive to the message (see Section 9.5).

The modern model of global agri-food enterprise tolerates little deviance from the commodity-based uniformity of mass produced and processed foods. Since the model has proven profitable, food systems nearly everywhere evolve following the same mould. Trade agreements and financial arrangements are structured to support its continuity and ubiquity. Through this process, agrobiodiversity is diminished, food options are constrained and nutritional needs are neglected. So why has change not taken root?

9.2.2 Lock-ins and path dependence

One reason the current system has persisted, deepened and expanded over the years despite increasing knowledge indicative of negative externalities, is due to what is known in evolutionary economics as "path dependence" (Nelson and Winter 1985). Theorists of societal response toward innovation and change have often noted that shifts in the *status quo* have often led to push back and blockage by those who have interests in maintaining the current system. Additionally, they have observed that "history matters"; the trajectory of economy, technology and society is largely predetermined by what came before.

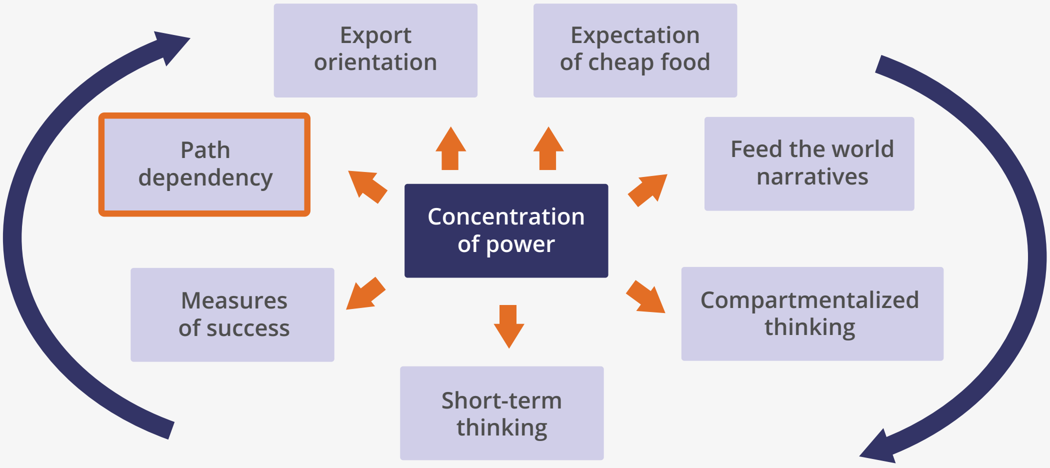
In order to explain how different policies open up or close down pathways for future development, Arthur (1989) and David (2007) pioneered the concept of lock-in and path dependency. Some policies lock us in to specific technologies and power relationships (industrial agriculture for example) and others leave open future possibilities (preserving large intact rainforests or wetlands, for example). A seemingly minor change can either open up new possibilities or restrict future options (see **Box 9.1**).

Path dependence is equally present in the case of food systems. Chhetri *et al.* (2010) simulated the ability of corn farmers in the Southeast United States to adapt to climate change based on their ease of exit from current agricultural technologies. Their model predicted substantial losses in corn productivity due to technological lock-in and the unpredictability of future climate regimes. Brown *et al.* (2014) used path dependency analysis to look at the potential for carbon sequestration from new woodland planting in Scotland in contrast to the conventional planting that would lead to net emissions. The International Panel of Experts on Sustainable Food Systems report (IPES-Food 2016) showed path dependency to be among the eight characteristics of industrial agriculture that most restrain advance toward sustainable food systems, **Figure 9.2** shows how path dependency has contributed to lock-in to a specific path in which the concentration of power plays a central role along with other drivers and narratives that help to perpetuate the system (see section 9.3 for further details of the importance of addressing power relations as a means toward transformational change).

Box 9.1 Path dependency and the QWERTY keyboard

The classic example of the restrictions brought by path dependency is that of the QWERTY typewriter keyboard that became widespread with the success of the Remington typewriter in 1878. The QWERTY layout (named after the first five letters in the keyboard's letter arrangement) was meant to avert keys jamming, common in the Remington when typists achieved greater speed. That is, the keyboard layout was intentionally designed to avoid hitting common key combinations in rapid succession, placing them on opposite sides of the keyboard. Even though other keyboard layouts are more ergonomically efficient and healthful (the Dvorak keyboard, released in 1932, for example, saves considerable finger movement and stress over the QWERTY), once the original keyboard became established, inertia made it impossible to dislodge. People learned to type on QWERTY keyboards, manufacturers were locked-in by consumer demand, and the layout persists to this day.

Figure 9.2 Eight key lock-ins of industrial agriculture (Source: IPES-Food 2016)



Path dependency can also be harnessed for positive change. For example, the success of electric cars has reached such a critical mass that is has spurred research and technological advances in battery efficiency. These advances further "lock in" the electric car industry in a positive sense. Other such positive synergies are found in food systems, for instance with consumer concern about the health effects of saturated oils or more recently with corn-based sweeteners. After a certain point in the gradient of adoption, avoidance of such ingredients becomes a new industry norm, and thus achieves its own path dependency.

These examples suggest that although path dependency can lead to an organisation or sector becoming locked-in to a particular technological or organizational paradigm, change is still possible. Consistent with the TEEBAgriFood ToC, to effectively intervene agents of change must work at the systems level and be aware of social, spatial, temporal and symbolic dimensions of change (Sydow *et al.* 2009). Furthermore, because lock-ins may be caused by resource "stickiness" or sunk costs, the costs of change may further constrain perceived options and flexibility.

9.2.3 Why we need a theory of change

Public policies can be formulated and evaluated based on real-world behaviour in the context of non-market interactions, incomplete or excessive information, and pervasive market and government failures. Explicitly considering complexity and evolution in public policy gives rise to a rich field of inquiry, embracing diversity, bounded rationality, social interaction, path-dependence, and self-organization (Gowdy *et al.* 2016).

An emerging field of inquiry dubbed the "science of intentional change" or "directed evolution" uses some basic principles of evolutionary theory to understand and shape future development paths (Waring *et al.* 2015; Wilson and Gowdy 2013; Wilson *et al.* 2014). An evolutionary approach can address the apparent conflict between the rigidity of top-down planning and the chaos of unrestrained markets. There is a need to overcome the "silo effect", that is, a separate set of researchers and policy makers forming around each issue. To avoid this, it is important to develop a policy framework that can be applied to a diversity of policy issues—now more than ever, given extreme inequality, the prospect of disruptive climate change, and the loss of biological and cultural diversity. A combination of complexity theory and evolutionary theory has the potential to provide this general theoretical framework. Additionally, successful interventions against path dependencies have been made based on an understanding of group behaviour, as in anti-smoking and anti-littering campaigns (Richerson *et al.* 2016). These interventions relied on mobilization of collective interests

The theoretical economic framework for pricing nature to "internalize externalities" comes from neoclassical welfare economics, where the basic tools of cost benefit analysis such as "Pareto efficiency" and "shadow prices" originate. The core model of standard welfare economics assumes that individuals are perfectly rational and self-regarding. It also assumes that by "getting the prices right" it will be possible to overcome market failures through reallocation, thus permitting externalities to be internalized. However, this approach erroneously assumes that all externalities are reflected in the rational actor model of human preferences, and that to resolve them requires simply aggregating those preferences to reflect societal concerns. Nevertheless, a fundamental theorem of welfare economics asserts that there is no logically consistent way to aggregate the preferences of diverse individuals.[2]

Yet behavioural economics has shown that people are in fact tremendously influenced by the behaviour of others. Humans are social animals, not entirely atomistic or selfish. What is needed, then, is to expand the boundaries of analysis to include complexity and feedback loops as well as consensus building and collective action. Ostrom (1990) and her followers did pioneering groundwork on the conditions for successful collective approaches to resource management that explicitly reject individual-based agendas. Ostrom and others showed that effective mobilization may arise from a combination of individual transformation and collective organization:

> *Attention is turning toward understanding and facilitating the role of individuals in collective and collaborative actions that will modify the environmentally damaging systems in which humans are embedded. Especially crucial in moving toward long-term human and environmental well-being are transformational individuals who step outside of the norm, embrace ecological principles, and inspire collective action* (Amel *et al.* 2017, p.255).

A collective action approach is needed to address the externalities associated with food systems. Such an approach explicitly recognizes biodiversity and ecosystem services as social goods. How these services are used by human societies becomes not only a matter of individual choice but also collective decision making for the common good.

An active role for government policy

The proper role of government has often been seen as limited solely to smoothing out the operation of the market by making sure externalities are properly priced and that property rights are fully assigned. But making a sharp distinction between the state and the private sector is misleading. Markets have always been shaped, supported, and constrained by government actions. As Polanyi (1944, p.140-141) put it: “The road to the free market was opened and kept open by an enormous increase in continuous, centrally organized and controlled interventionism.” Indeed, for Polanyi, land, labour and money represent “fictitious commodities” as they are not created but have value conferred by the social system within which they exist and the political structures which regulate their access and use. The creation and progressive adaptation of institutions that regulate these values has occupied much of history.

Mazzucato (2015) argues that inclusive and sustainable development requires rethinking the role of government in promoting the public good — supporting not only innovation but also its direction. Building on Keynes, Mazzucato argues for an even more robust role for government, one that requires shaping and creating new markets. In this scenario, long-run public prosperity can take the place of short-term private greed. Economists have long recognized the role of the government in protecting the public good against the excesses of the unregulated market. Public policies based on scientific understandings of the natural world and human social systems can redirect the trajectory of the global economy to ensure environmental and social sustainability.

> *The important thing for Government is not to do things which individuals are doing already, and to do them a little better or a little worse; but to do those things which at present are not done at all.* — Keynes (1926, Part IV)

As mentioned above, temporal and spatial characteristics of change also need to be considered when contemplating intervention. The time period of analysis should be long enough to consider complex interactions and regular changes in external conditions. A policy that appears to be successful at one point in time may not be successful when conditions change. One example is pesticide resistance. It is not enough to observe the immediate effects of introduction of a pesticide or herbicide, which are usually quite positive in terms of crop yields. Policy makers need to consider how whole ecosystems evolve over time. We know that pesticide resistance evolves but does it evolve faster in some systems than in others? Does monoculture facilitate pesticide resistance? Or, as **Figure 9.3** describes, have pesticides simply substituted one predator for another?

Many of the challenges we face lie in the realm of what has been called “post-normal science”—characterized by extreme uncertainty and the possibility of catastrophic consequences of inaction (Funtowicz and Ravetz 1992). The global economy is a very complex evolutionary system, efficient in finding productive resources and creating economic value. Yet predicting the consequences of cumulative stress on the resilience of natural capital is difficult and controversial. There are no market signals to warn the economy of the distant but likely severe consequences of ecosystem disruption, for example, the effects of climate change in 50 or 100 years. The question is whether our fate as a species will be left to the whims of blind evolutionary forces or whether we can collectively change our trajectory with recourse to ethics, science, and reason. Can we alter the path of our social evolution? Can our global civilization take a new path toward an ethics based on collective responsibility for the common good, and, if so, what are the implications for change in food systems?

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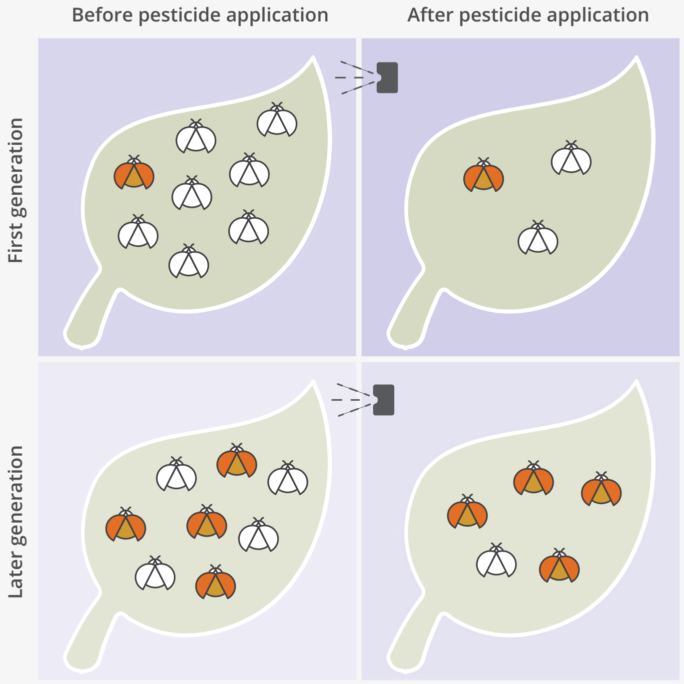
[2] These represent, respectively, the First, Second and Third Fundamental Theorems of Welfare Economics (Feldman 2008).

Figure 9.3 Figure 9.3 Time sequence of pesticide resistance in pest populations (Source: https://commons.wikimedia.org/w/index.php?curid=3965987)



9.3 TRANSFORMATIONAL CHANGE IN ECO-AGRI-FOOD SYSTEM GOVERNANCE

Governance systems have traditionally been characterized by path-dependencies, as one of their main functions is to create and reproduce norms and institutions. As previously discussed, path-dependencies have in many cases undermined instead of supported environmental protection. This has contributed to lock-ins in eco-agri-food systems, which have in turn led to soil depletion, loss of biodiversity, and negative health impacts (TEEB 2015; Thompson and Scoones 2009).

With the increases in environmental degradation, climate risk and uncertainty - key challenges of the Anthropocene - there have been increasing efforts to develop new forms of governance to facilitate transformation. **Adaptive governance** incorporates flexibility into response strategies in order to respond to uncertain environmental risk (Folke *et al.* 2005), but such incremental adaptations are not always successful (Tschakert *et al.* 2010). Where risks and vulnerability are particularly grave or imminent, transformational adaptation is needed. Transformational adaptation refers to solutions that are both reactive and anticipatory in nature (Kates *et al.* 2012). For example, responding to major climate change in agricultural areas may require revised livelihood strategies and diets, as well as changes in farming practices and food systems (Rickards and Howden 2012; Vermeulen *et al.* 2013).

Anticipatory governance refers to decision-making processes that rely on foresight to reduce risk and increase adaptive capacity (Quay 2010). These include worst-case scenario strategies, or undertaking actions that work well in a variety of scenarios (Lempert and Schlesinger 2000). Governance processes that facilitate ongoing adaptation, long-term planning and proactive learning support **anticipatory governance** (Boyd and Folke 2012; Boyd *et al.* 2015). The TEEBAgriFood Framework can facilitate effective anticipatory action, as it incorporates the precautionary principle and supports development of scenarios and their quantification, and makes use of dynamic systems modelling tools for long-term planning (TEEB 2015).

The risk of future lock-in along new pathways – even with adaptive flexibility – leads to a need for transformative governance: "an approach to environmental governance that has the capacity to respond to, manage, trigger regime shifts in social-ecological systems (SES) at multiple scales" (Chaffin *et al.* 2016, p.399). Such transformations involve the development of new knowledge, the creation of social networks to build coalitions for change, the emergence of leaders shaping visions and guiding change, the seizing of windows of opportunity and the creation of enabling legislation (Ernstson 2011).

Achieving flexibility in governance processes requires institutions that are able to deal with changing SES contexts (Dryzek 2014). The ability to change course in response to reflection on and assessment of performance, is the opposite of path-dependency (Dryzek 2014). It implies self-critical capacity, in that a reflexive institution is able to recognize failure and learn from it (Beck *et al.* 1994). In line with the aims of TEEBAgriFood, such reflexivity enhances the capacity to take into account and value ecological systems as a basis for change in decision-making processes (Dryzek 2014; Folke *et al.* 2010).

In current agri-food governance systems, specific political economy contexts impose path-dependencies linked to entrenched power structures that disregard ecological values. The question here becomes: how can we transform governance systems in a way that weakens unsustainable path-dependencies while building ecosystemic reflexivity?

Based recent evidence-based guidelines for policy transformation in natural resource arenas (Young and Esau 2016), we identify four areas of action that can support transformative governance in food systems. These action areas are meant not only to help to overcome path dependencies, but also to facilitate and maintain innovation towards sustainable, resilient and integrated eco-agri-food systems.

9.3.1 Ideas, knowledge and narratives – building a common language across silos

Unsustainable food systems are maintained in part by dominant narratives on industrial farming practices that encourage extreme specialization, increased productivity of commodity crops, and increased agricultural trade flows as the way to deliver food security in an overpopulated world. These 'feed the world narratives' have proven very popular despite evidence of the failures of industrial agriculture (Dryzek 1997; IPES-Food 2016; Lang 2010). Similar approaches to food security and nutrition have focused on supplementation and biofortification, whether through crop improvement or genetic manipulation with little attention to other ways to improve peoples' access to diverse diets. Nevertheless, a variety of narratives have emerged over the years that advocate for a shift from a conventional to a sustainable development paradigm in eco-agri-food systems.

From food security to food sovereignty narratives. Counter-narratives to the prevailing "feed the world" narrative can challenge social norms and achieve both local and global impact (Fairbairn 2012; Lang 2010; Martinez-Alier 2011; Phalan *et al.* 2016; Wittman 2009). For example, the Food Sovereignty Movement, which emerged in the 1980s, challenges the definition of food security grounded in increasing individual purchasing power (Edelman 2014) by means of large-scale mechanization and globalized food systems (Jarosz 2014). Instead, the food sovereignty movement aims at "transforming …food systems(s) to ensure…equitable access, control over land, water, seed, fisheries and agricultural biodiversity." (IPC 2009 cited in Jarosz 2014: 169). The movement adopts a rights-based approach that emphasizes sustainable family-farm based agricultural production and supports diversification and localization of food systems.

First developed by social movements of farmers such as La Via Campesina, this discourse has also been adopted by an increasing number of NGOs such as Slow Food and Food First. Thanks to years of advocacy, the food sovereignty narrative is now more accepted among multilateral organizations such as FAO and the World Bank. Advocates describe food sovereignty and a rights-based understanding of food security as complementary with access, distribution, security and equity, and the use of these narratives has stimulated a variety of global and local initiatives (IAASTD 2009). Global impacts include the development of the 'slow food' and the 'farm to fork' discourses and the inclusion by the FAO Council of the right to adequate food (Foran *et al.* 2014). Local level initiatives include the People's Food Policy Project in Canada and the Australian Food Sovereignty Alliance, both of which engage people in food policy decisions, and the Detroit Black Community Food Security Networks which focus on self-reliance of black communities (Schmidt 2012 cited in Jarosz 2014; White 2002 cited in Jarosz 2014). Yet food sovereignty movements have been less effective at addressing certain systemic challenges of eco-agri-food systems, such as cross-scale coordination and rural-urban linkages.

The true cost of food. Discourses on food security also include the idea that we need 'cheap food to feed the world'. Such narratives are based on cultural framing that emphasize 'cheapness, convenience… and rendering invisible the origins of food products' (Campbell 2009 cited in McMichael 2014, p.160). They contribute not just to perpetuating unsustainable food systems, but also to increasing nutritional gaps between rich and poor, with health diets catered to the affluent and highly processed food to poorer populations, leading to both malnutrition and obesity (Dixon 2009). To counter such narratives, it is necessary to expose the true cost of food, and clarify how healthy diets and sustainable food systems require externalities to be incorporated in the actual cost of food. Such counter-narratives need to be supported by more complex scientific evidence and feedback mechanisms including science-policy interface processes to back arguments in negotiations with incumbent vested interests (Young and Esau 2016). TEEBAgriFood provides new evidence on costs and benefits that contributes to counter-narratives that take ecological values into account, exposing the true cost of food.

Agroecology and the shift from productivity to resilience narratives. Beginning in the 1970s, the discourse around agroecology directly challenged the productivity argument of dominant industrial farming practices. Agroecology concepts began to influence production practices, and contributed to the defining of sustainable agriculture (Wezel *et al.* 2009; Douglass 1984). In the 1990s, the field of agroecology expanded to include a more complete view of the global value chain of food production, distribution, and consumption, (Gliessman 2007; Francis *et al.* 2003; Kremen *et al.* 2012) calling for eco-agri-food systems that are robust and resilient (Gliessman 2007). Schipanski *et al.* (2016) suggest four integrated strategies to foster food system resilience: integrate gender equity and social justice in food security initiatives, substitute ecological processes for the use of external inputs, support localization of food distribution and waste collection and build a stronger link between human nutrition and agriculture policies.

Dissemination of such counter-narratives is essential to develop a strong case for change, reorient attention and secure political support for formulation of new agendas, rules and policy actions (Young and Esau 2016). To be effective it is important that such narratives are simple and unambiguous, and that they provide clear vision and outcomes. However, such narratives also need to be supported by scientific evidence to back arguments in negotiations with incumbent vested interests (Young and Esau 2016). TEEBAgriFood provides new evidence on costs and benefits that take ecological values into account. In general, the creation and spread of new narratives requires collective action as well as a certain critical mass of support, which is often facilitated through the work of social movements.

Agroecology represents a major paradigm shift and has triggered a variety of different initiatives and innovative social arrangements, some more successful than others. Together, they represent a powerful force for change on how we think about food systems. However, no narrative is immune from discursive struggles. The appropriation of the concept of 'agroecology' by different constituencies has led to distinct interpretations and differing agendas (Francis *et al.* 2003; Levidow 2015; Wezel *et al.* 2009). The risk that powerful transformative narratives may be co-opted is always present (IFA 2015).

Dissemination of such counter-narratives is essential in order to develop a strong case for change, reorient attention and secure political support for effective agenda setting and support the formulation of new rules and policy action (Young and Esau 2016). To be effective it is also important for such narratives to be simple and unambiguous, providing a clear vision and outcomes. In general, the creation and spread of new narratives require a certain critical mass of support, which is often facilitated through the work of social movements.

9.3.2 Redirecting structural power and financial resources

One of the most demanding aspects of transformative governance is tackling structural power. Structural power refers to the power that is conferred to actors due to their position in society. It is reflected in how state actors internalize interests of key business sectors. It often translates to 'inaction', which in our case is shown in the lack of progress towards policies supporting sustainable food systems, or in the reversal of existing supportive policies (Newell 2012).

Efforts to both challenge and persuade vested interests to change course are in progress in many contexts worldwide. In agri-food systems this effort may entail either confronting or encouraging change by multinationals engaged in agricultural input production, agribusinesses, distribution and retail chains as well as the state structures that support them. Four approaches that can assist in shifting the constellation of power are: 1) Lending legitimacy and voice to existing challengers, 2) Engaging with vested interests to facilitate public commitments, 3) Building new political alliances and identifying effective policy entrepreneurs to lead these alliances, and 4) Facilitating new polycentric modes of governance that bring more voices to the table to challenge dominant vested interests.

The first approach entails lending legitimacy and voice to initiatives that support more sustainable food chains, such as Alternative Food Networks or agroecological approaches to farming. Because of the resources and formal authority that they command, state actors and intergovernmental bodies have particular power to contribute to legitimize existing initiatives. Yet legitimacy is not just bestowed by state actors embedded in hierarchical governance structures, but instead by a variety of different sources that can be mobilized by non-state actors (Bulkeley *et al.* 2014; Klijn 1996). Sources of authority include the recognition of expertise, the ability to forge consensus among different actors, and the effectiveness in delivering results.

A second approach is to directly engage with large agribusiness and processing companies and distributors along the value chain to facilitate public commitments and voluntary agreements to increase sustainability of eco-agri-food systems. Such efforts have been facilitated by large environmental NGOs, such as Greenpeace, the World Wildlife Fund (WWF) and The Nature Conservancy (TNC) as well as by government agencies in collaboration with leading multi-nationals (see Section 9.4.1 on multi-stakeholder initiatives) (Cattau *et al.* 2016). Yet self-regulation has also been criticized for lacking ambitious enough targets and falling short on prospective aims (Meijer 2015; Oosterveer *et al.* 2014; Ruysschaert and Salles 2014). More recent pledges and commitments, such as the New York declaration on Forests, are more ambitious in their targets and include pledges by single identifiable companies (Zarin *et al.* 2016). Publicity of such commitments builds reputational accountability mechanisms to which brand-based businesses are particularly sensitive.

A third way to facilitate transition to more sustainable food systems is to build coalitions and forge new political alliances with state and non-state actors. Engaging with a variety of actors is important to achieve broad support. Reformist organizations and visionary policy entrepreneurs are essential to such coalition building (Freedman and Bess 2011; Young and Esau 2016). Without powerful policy coalitions, it is difficult to reverse policies that provide perverse incentives and subsidies in the agricultural sector (Bruckner 2016; Nesheim *et al.* 2014). Most reformist movements, such as the food sovereignty and the localization movements, have their basis in social movements, (Rosset and Martinez-Torres 2012) and although they face the risk of being co-opted, it can sometimes be necessary to ally with powerful established actors in order to influence agenda setting (Van Dyke and McCammon 2010).

The fourth approach to shift structural power is to facilitate new modes of governance in eco-agri-food systems that are polycentric, multi-level and deliberative. Polycentric processes have a greater chance of increasing inclusiveness of views and breaking up vested interests in dominant policy communities, as compared to relying on hierarchical state dominated structures (McGinnis 1999). One feature of eco-agri-food systems that reinforces path-dependencies is the high concentration of private power, including the power to dominate government policies (Bellamy and Ioris 2017). Developing governance structures that have multiple platforms and entry points into political systems multiplies the centres of power, and leads to more diffusion of power overall. Devolution of power has also been shown to facilitate cooperation at the local level among farmers and to facilitate adoption of conservation practices (Marshall 2009). Furthermore, deliberative decision making processes in polycentric governance structures help to break up path-dependencies, thus strengthening reflexivity (Dryzek 2014). This suggests that facilitating multi-stakeholder and multi-level processes can help provide platforms for less powerful voices at different levels of governance. Recent research has provided examples of framework approaches for such facilitation (Hubeau *et al.* 2017), which have promoted increased experimentation and opportunities for learning. Integrated landscape approaches support such stakeholder processes that entail recognition and participatory negotiation of diverse stakeholder interests in the context of multi-functionality of landscapes (Shames and Scherr 2013; Reed *et al.* 2016).

9.3.3 Financial resources to maintain momentum for implementation

Even when shifts in structural power are achieved and new policy decisions are agreed upon, it is important to maintain the momentum during implementation of policies. Careful design and detailed policy proposals that aim to demonstrate benefits early on can help to maintain political support and funding for implementation (Young and Esau 2016). Given the lack of long-term reliability in public funding, it is best to further embed funding within regulatory market processes to help sustain financial flows over time (Salzman 2016).

In order to support transformation in eco-agri-food systems, financial resources need to be allocated to state agencies as well as to non-state actors working on smallholder services that focus on long-term resilience and adaptation in agroecological systems. Resources may need to be diverted from national levels in order to support local and cross-level processes of integration (Blay-Palmer *et al.* 2016). This includes providing incentives to local innovation processes (which tend to be more diversified and resilience focused) as well as cross-sectoral and cross-level coordination to support policy coherence. Integrated landscape approaches put particular emphasis on cross-scale collaboration between sectors, policy actors and social groups, and require that joint investment planning processes among stakeholders are adequately funded (Shames *et al.* 2017).

9.3.4 Adaptation and learning

Transformative governance is highly dependent upon adaptation and learning processes, including flexibility in decision-making and implementation, and the ability to recognize failure and learn from it. Policy experimentation and inbuilt mechanisms that allow redirection of policy decisions are key. One simple step to embed learning in policy processes is through a formal periodic reviews (Young and Esau 2016). These reviews should insure that the political, practical and scientific results of the policies reflect the intended objectives of the reform agenda. Adopting the TEEBAgriFood Framework would ensure that ecological values and ecosystems services are assessed when examining an eco-agri-food system.

In any adaptive system, trial and error approaches are part of the policy design, and help to fine-tune of policies as they are enacted. The need for adaptive responses in the eco-agri-food system is particularly important because these systems are subject to a variety of shocks which threaten food security, including climatic, socio-economic, and political issues (Thompson and Scoones 2009). With increasing climate change impacts and related uncertainties, adaptation becomes more important (Porter *et al.* 2014). Agroecological approaches have been proven to be more adaptive and resilient to climate variability than traditional agriculture (Altieri *et al.* 2015). Maintaining the biodiversity of eco-agri-food systems, addressing trade-offs in intensification, reducing environmental impacts, investing in local innovation, discouraging the use of highly productive land for animal feed, and building resilience through the support of local food systems can all contribute to build more adaptive eco-agri-food systems (Cook *et al.* 2015). Integrated landscape approaches and management can contribute to support more sustainable eco-agri-food systems (Freeman *et al.* 2015; Milder *et al.* 2011). Furthermore, built-in mechanisms that support "triple wins" that achieve climate change adaptation, mitigation and development simultaneously will support resilience and long-term sustainability (Di Gregorio *et al.* 2016; Nunan 2017).

Finally, learning and a willingness to experiment are crucial to facilitate transformation. If we understand governance as a social learning process, it becomes crucial to maintain the capacity of different government agencies, experts, actors along the value chain and consumers to negotiate goals and translate them into shared actions. 'Single-loop learning', which aims at improving results in day-to-day management practices, should be included in policy processes though formal evaluation. 'Double and triple-loop learning' are also important in adaptive and transformative governance practices (Pahl-Wostl 2009). Double loop learning helps to question the assumptions behind the very questions we ask and can thus lead to reframing, a fundamental process for disseminating new ideas and narratives (Argyris and Schön 1978). Triple loop learning reconsiders values and beliefs when assumptions no longer hold and is associated with paradigm shifts that rewrite social norms and transform institutions (Armitage *et al.* 2008). Both reflection and anticipation are needed for double and triple loop learning and these need to be explicitly built into policy-making as well as implementation processes.

Anticipatory learning focuses on the future and is particularly important for resilience and long-term planning. It involves learning from the past, monitoring and anticipating events, deliberately assuming potential future surprises, measuring anticipatory capacity and designing adaptive decision-making mechanisms (Tschakert and Dietrich 2010). Implementing the TEEBAgriFood Framework can support a number of learning objectives, as TEEB is based on a sustainable development paradigm, which includes the adoption of the precautionary principle, a long-term vision, and the inclusion of non-market values in decision-making. As such it runs counter to the current traditional eco-agri-food policy paradigm that is reactive, short-term and market-based.

9.3.5 Lessons learned for change

The TEEBAgriFood Framework benefits from the experience and lessons learned from the core TEEB initiative since the mid-2000s as well as reflection on parallel initiatives. For example, TEEB (2010) recommended the inclusion of ecosystem services values into business decision making to improve biodiversity management. To bring these values into the mainstream would require that natural capital be considered routinely in corporate strategies and operations.

Collaborative problem solving among stakeholders across sectors and competencies is required in order to achieve a common purpose with enduring policy and business ramifications. Many of those involved in the development of different approaches for business application of natural capital joined forces to form a space for collaboration, the Natural Capital Coalition. The Coalition built on the initial work of TEEB to harmonize the existing approaches into one overarching framework, the Natural Capital Protocol, launched in July 2016 (see Section 9.4.4). The Protocol helps business to identify, measure and value their impacts and dependencies on natural capital. Such information and subsequent reporting allows businesses to better manage their natural capital risks and opportunities in a transparent fashion. The ability of the Protocol to support evolution in business policy and practice informs the approach toward intentional change promoted through TEEBAgriFood, as we seek to effect business responses and value changes while working to nurture a group of diverse communities united toward change.

9.4 TEEBAGRIFOOD'S CONTRIBUTIONS TO CHANGE

This section reviews current business, policy and societal responses to the threats posed by food system externalities, including efforts to confront path dependencies, and to learn from past efforts to unite stakeholders in the search for alternatives. These include, inter alia, the undertaking of multi-stakeholder and round-table processes concerning common principles and criteria for food certification, and the role of localization and food movements on inciting change. Valuation of heretofore "invisible" costs and impacts can and has been used to effectively support drivers of change and to launch responses on the part of diverse actors in the food system. Here we highlight the roles of key influencers, allies, adversaries and messengers. The objective is to show how applying the TEEBAgriFood Framework can support current and prospective initiatives to bring change to food systems.

In section 9.2, above, we showed how additional information on food system externalities, while valuable in and of itself, may be insufficient to change value chains. Path dependencies and lock-ins have impeded innovation, as have mainstream economic perspectives that have fundamental limitations for collective action. In section 9.3, we discussed the institutional preconditions for transformational change in eco-agri-food system governance.

Here we show how key actors in the eco-agri-food system can seek synergies among them that may encourage systemic change. We draw from cases presented in this and other chapters in this report to illustrate this discussion. Signals of need for change (social mobilization, boycotts, scientific and moral condemnation) became reflected in actions affecting the food system, such as third-party monitoring of moratoria on deforestation for soybean production or certification of valuable trade commodities such as coffee, cacao and others.

The intent of this section is to show the broad array of entry points for TEEBAgriFood to influence existing structures in the food system, as well as to inform and be informed by parallel initiatives underway. Both the actors and the ways in which these processes seek to influence change differ, and thus could be described as offering distinct "theories of change".

The evidence regarding external costs of eco-agri-food production and claims of global institutions in international forums have stimulated some firms to initiate change in agribusiness behaviour towards adoption of more sustainable practices. A small percentage of end consumers along with targeted NGO campaigns have helped spur change in this direction.

Such change has also come through the pressure of regulations introduced by policymakers to reduce external costs or provide offsets for compliant practices (e.g. EU agroenvironmental measures). Although some changes are policy driven, there are other forces that can drive change in agribusiness practices, e.g.: (i) financial institutions' introduction of sustainability requirements to access funds, (ii) large companies on the value chain (e.g. manufacturers, retailers) introducing sustainability requirements for purchasing products (e.g. sustainable provision of wood, palm oil), (iii) consumers willing to pay for sustainable products (eco-business), and (iv) non-governmental organizations and the media benefiting from the significant repercussions to be had by making claims against unsustainable practices or promoting sustainable ones.

Consequently, farmers and agribusiness managers have been compelled and/or inspired to move from a 'reactive' towards a 'proactive' stance. Foreseeing the potential risks and opportunities linked to natural, social and human capital and their management has come to represent a basis for competitiveness (Porter and Von den Linde 1995). International competition in global markets has led farmers and agribusinesses to recognize that those unable to properly manage their risks and to seize opportunities will not succeed.

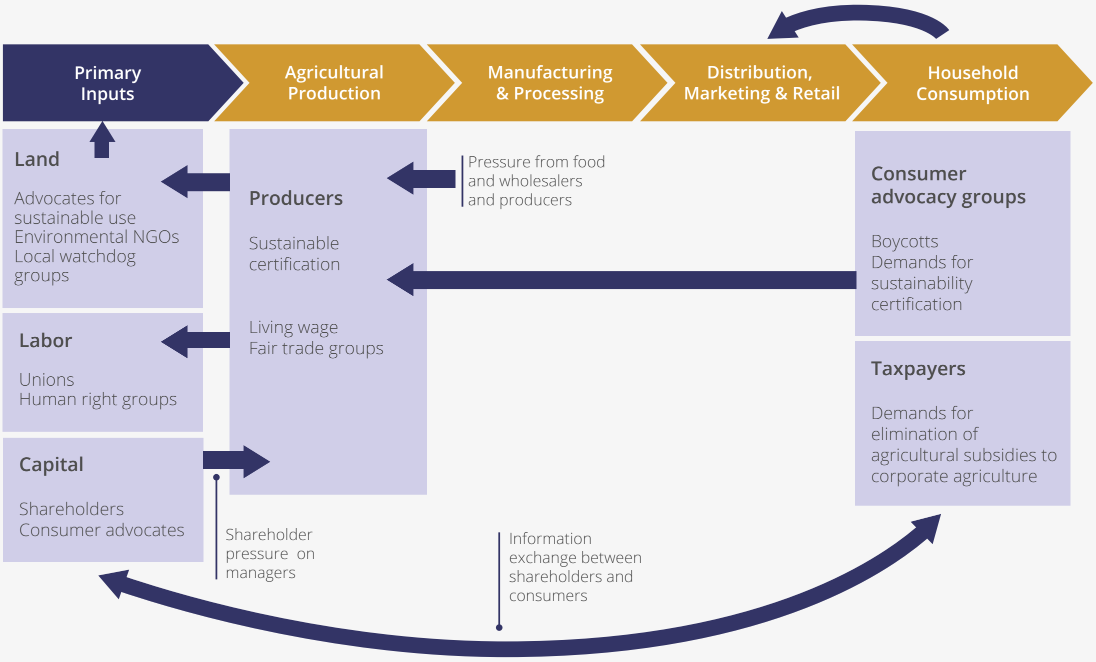
For example, ubiquitous consumption, particularly among low-income groups, of foods and beverages containing maize-based high fructose sweeteners is increasingly viewed as related to obesity and diabetes, although business interests suggest sedentary behaviour is more at fault than an improper diet (Hawkes *et al.* 2015). Nevertheless, hundreds of products now proudly advertise their brands as being free of such sweeteners as a response to consumer concerns. A proactive strategy might be to promote healthy dietary alternatives while seeking other profitable uses of surplus maize (or removing perverse incentives). Further evaluation of their externalities is a necessary step to respond more fully to these pressures.

9.4.1 Strategic campaigns and multi-stakeholder initiatives

Beginning in the 1980s, concentration within globalized agri-food value chains endowed multinational firms with increased negotiating powers. At the same time, globalization has increasingly disconnected the places of distribution and consumption from the places where commodities are produced (Porter 1998). This was accompanied by a parallel reorganization of civil society organisations (CSOs and NGOs), who adapted to the increased concentration in the food industry by restructuring themselves to mirror the changing structure of the multinational companies (Palpacuer 2008).

The role of different stakeholders in change processes must therefore be approached via their role in the value chains (Forrer and Mo 2013; Kashmanian and Moore 2014). Figure 9.4 describes the critical points along food systems on which CSO/NGO coalitions have acted jointly with progressive business organisations, consumers, taxpayers and labour advocates to place pressures upon the formation of value chains. By strengthening flows of information and other resources, such coalitions have served as enabling agents of transformational change.

Figure 9.4 Transformational change through strengthening the connections in the value chain, indicating key pressure points (arrows) (Source: authors)



The upsurge of involvement of NGOs in the critique of agri-food value chains reflects an evolving perception of their role in society as agents of change. There is a growing recognition that downstream segments of the agri-food value chain (i.e., distribution, consumers) can influence nodes on the production and inputs end. Putting pressure on brands and on distribution firms forces them to turn to their suppliers and demand (and pay) for more sustainable products; this should in turn force the suppliers to ask for more sustainably produced raw material, and so on, back up to the producers. Once this movement is initiated, it can progressively become mainstream in the whole industry as competing firms align to preserve their market shares. Increasing the negotiating power of the producers can allow them to change their production system towards one that is more sustainable (e.g. sending children to school instead of to the fields, creating better working conditions and wages for agricultural workers, reducing the use of pesticides, eliminating the cutting down of high value forests, etc.).

Social justice and rights-based NGOs were the first to adapt to increased concentration in the agri-food industry and to design campaigns targeting brand owner companies. They pressured firms to better discriminate their supply sources and to dispense with the most irresponsible companies. The first campaigns of this type were carried out by North American organizations aiming at textile brands, forcing the companies to impose guarantees on their suppliers concerning working conditions and in particular to prohibit child labour (Armbruster-Sandoval 2003). Environmental NGOs later followed their lead.

Two examples of this process include the case of soybean production in Brazil and palm oil production in Indonesia. Soybean crops, mainly grown for cattle feed, are implicated in deforestation pressures in Brazil (Macedo *et al.* 2008). These pressures were the subject of a major campaign by Greenpeace entitled “Eating up the Amazon” (Greenpeace 2006), and later “Slaughtering the Amazon” (Greenpeace 2009) to refer more specifically to cattle ranching, denouncing the progression of deforestation and slavery.

These campaigns were widely publicized and targeted the large agri-food companies that controlled the bulk of exports (Cargill, ADM, Bunge and AMaggi) as well as banks (IFC and European banks). They also targeted the main actors of the European meat sector, including fast food chains and traders. The action took place at the end of a period of major agro-industrial expansion in Brazil, at a time when some governmental measures against rampant deforestation had been undertaken (Nepstad *et al.* 2014), but NGOs found these measures insufficient to bring significant reduction in forest degradation. Supporting the narrative was robust scientific evidence from satellite monitoring systems showing large-scale conversion of forest to soy between 2001 and 2006. This evidence was instrumental in recruiting major retailers such as McDonald's to act and sign the first zero-deforestation agreement in the tropics.

As a result of this campaign, and with the help of low prices at that time, the change in the power relationship gave birth to a renewed dialogue between the major stakeholders of the industry (led by the oilseed crushers' association ABIOVE), the government and NGOs (Cooper 2009). This resulted in the first historical example of voluntary industry-wide individual commitments to a "zero deforestation" policy, known as the "soy moratorium". Monitoring systems able to identify violating farms facilitated enforcement of the policy and reported a high compliance level (Kastens *et al.* 2017; Rudorff *et al.* 2011).

This wholly voluntary measure is now considered one of the decisive factors in securing broader agricultural sector commitments toward reducing the deforestation of the Amazon. Proposals for its termination and to pass control to government regulation after ten years were considered premature, due to the need to resist the surge in deforestation that has been associated with the current Brazilian economic crisis However, the current overall effect of these commitments on the transformation of practices and ultimately on deforestation and working conditions are still uncertain (Aubert *et al.* 2017a).

Palm oil in South-East Asia represents yet another major example of a campaign that resulted in corporate commitments to sustainable production concerns. Responding to the growing concerns about deforestation in Indonesia and Malaysia, WWF built upon its experience with forest certification (having been the initial sponsors of the Forest Stewardship Council), and launched a certification platform for sustainable palm oil production (Roundtable on Sustainable Palm Oil, RSPO).

While RSPO was taking a growing share of the market, some NGOs, particularly Greenpeace and Friends of the Earth, left the board and denounced the inadequacies of certification to combat deforestation and promote improved working conditions (see also in particular Poynton (2015)). The Greenpeace campaign was called "cooking the climate" (Greenpeace 2007) in reference to the effects of draining the Asian peat lands to allow for palm oil growing, which results in global warming. These campaigns targeted the major players upstream of the value chain, such as Golden Agri Resources, Golden Hope or Wilmar, followed by major downstream companies (Unilever, Nestlé, Procter & Gamble). Initial commitments were made by two major trading and processing companies (GAR, then Wilmar) as a result of the impact of these campaigns on brand reputation and consumers' behaviour. These oil palm players committed themselves to generate "zero deforestation, zero (use of) peat and zero exploitation" and go beyond the requirements of RSPO certification. These first commitments initiated a domino effect, when two other major operators (Cargill and Asian Agri) adopted the same pledge in September 2014, not only for their own operations but also for their suppliers and their affiliates.

In some specific cases, initiatives have been successful in bringing attention of the broader public to the relationship between consumption, production and sustainable food systems. However, the results have been mixed, and are often temporary until pressure is reduced. A more thoroughgoing theory of change presupposes the need for an enduring paradigm shift. Such a shift requires examination of hidden external costs to different actors in the value chain, and the development of adequate mechanisms to monitor and validate the commitments assumed by the industry.

9.4.2 Eco-agri-food certification processes

Certification and associated multi-stakeholder processes represent a phenomenon of the late 20th Century described as non-state regulation (Bernstein and Cashore 2007) that has been exceptionally effective in alerting society and responsible stakeholders of the need for better scrutiny of eco-agri-food supply chains. Although the State may be engaged as a participant, decisions are often reached by consensus among social movements or labour unions, and environmental and business representatives on the principles and criteria to be adopted across a given commodity or supply chain, enhancing the value of the product to the consumer.

Certification or sustainability standards emerged at the end of the 1990s, in parallel with rising critiques of the social and environmental impacts of globalized trade on labour conditions and on the environment. They are intimately linked with NGO campaigning, since certification can be seen as a way to respond to critiques with a collaborative approach. Standards have been implemented in the forestry and agriculture sectors for at least two decades with different levels of adherence across regions, crops or value chains.

The first certifications addressed trade (Fair Trade labelling), and forest protection (with the Forest Stewardship Council initiated by WWF). Certification initiatives were further developed in the 2000s around the issues raised by agri-food commodities, with soybean certification (Roundtable on Responsible Soy, RTRS), sugar (Bonsucro), sustainable palm oil (RSPO), or Roundtable on Sustainable Biomaterials (RSB).

The TEEBAgriFood ToC rests on the assumption that inadequate prices are paid to farmers and that insufficient attention is paid to agri-food production processes and their associated social relations by multinational companies and by markets in general. It is also based on observing a gap between the concern for social and environmental sustainability on the consumer side versus that espoused by traditional regulatory agencies, the latter tending to favour industrialization and economic growth at the expense of social and natural capital. The TEEB approach suggests certification should complement regulatory practice, which should serve as a point of departure for more rigorous quality demands. Revealing hidden external costs associated with unsustainable supply chains is a missing aspect in the development of certification. TEEBAgriFood studies can thus permit that certification become more effective in clarifying the need for greater investment in quality controls.

The intensity and speed of implementation of regulatory standards in a specific country is influenced by variables such as economy (GDP, export or national market), level of governance and the social context (van Kooten *et al.* 2005). It also depends on the organization of the production sector and its value chain and the visibility of the certified raw material as an ingredient or a final product for consumers (Pinto *et al.* 2014a). Nevertheless, substantial growth in standards compliance occurred over the past decade for crops such as coffee, cocoa, tea, forest plantations (mainly eucalyptus for pulp and paper) and palm oil (Potts *et al.* 2014). This growth is a consequence of increased consumer awareness and the leadership of food and other enterprises, which have made public commitments to source certified commodities and ingredients.

Although certification holds a prominent position in sustainability initiatives, its impact on development processes and natural capital conservation and its ability to lead transformations of eco-agri-food systems is still quite controversial. Despite an increase in number and area of certified crops, the overall impact of certification in improving social, environmental, agricultural and silvicultural performance in the field (though widely touted by certifiers and certified producers alike) is still limited and lacking in counterfactual evidence, as is credible scientific data about the impacts or performance of most initiatives (COSA 2013) [3]. When considered at a landscape scale, the offsite impacts of certification would be more significant if certification were combined with integrated landscape initiatives (Deprez and Miller 2014).

A recent comprehensive meta-analysis brought together the results of more than 40 studies and surveys from different sectors of the economy and their respective certification systems. Results concluded that sustainability standards offer a broad range of business benefits throughout an individual firm's supply chain that can be materialized in its corporate value and in the overall sector in which it is inserted (Molenaar and Kessler 2017). The study identified key short-term results: price premiums, market access, access to finance, better supply chain risk management and operational improvements. The long-term results identified included increased profits, lower costs and improved reputation. In agreement with the long-term expectations for the TEEBAgriFood Theory of Change, there is no final point – just continuous performance improvement as conditions and challenges constantly change (see Box 9.3).

Three of certification's ostensible objectives can help assess its actual or potential effectiveness to induce a change in eco-agri-food systems and relate to the TEEBAgriFood theory of change:

1. Increasing primary producers' remuneration in comparison to non-certified products, to compensate for certification requirements and to improve producers' economic and social situation, thus increasing their share of the value added, and fostering a commitment to sustainable production paths.

2. Initiating a change in the prevalence of practices decried in targeted sustainability issues: child labour, slavery, deforestation, etc.

3. Reaching a critical mass of primary producers in the regions concerned so as to achieve broader objectives for social and environmental sustainability.

Issues, doubts and ways forward are illustrated below with: (a) a case of a specific commodity certification, namely that of palm oil (**Box 9.2**) and (b) a case study of a number of certified supply chains in Brazil (**Box 9.3**). Although these two examples illustrate initiatives with respect to tropical deforestation, initiatives of this type are not restricted to such contexts. For instance, organic farming or other types of labelling may also address water quality, grasslands, the local origin of production, or animal welfare, etc.

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[3] This implies such measures as using good protocols, addressing counterfactuals, and statistical significance (COSA, 2013). COSA is a neutral global consortium of organizations whose mission is to accelerate sustainability in agriculture via practical assessment tools that advance our understanding of social, economic, and environmental impacts.

Box 9.2 Assessing palm oil certification impacts

Regarding the premium obtained on sale of certified palm oil, the various standard managing organizations (RSPO, International Sustainability and Carbon Certification-ISCC, and Rainforest Alliance) provide very little information. Although slightly dated, a report by WWF *et al.* (2012) indicates a premium of US$ 25 to $ 50 / ton (i.e. 2.5 cents / kilo) for RSPO certified oil, depending on the marketing mode. Aubert *et al.* (2017b), however, indicated a similar albeit slightly lower premium range for ISCC and for RSPO certificates, from US$ 20 to $ 40 / ton. Two assessments made by WWF (Preusser 2015; WWF *et al.* 2012) show that certification makes it possible to improve the productivity of a plantation (sometimes by 40 per cent or more) and to some extent to reduce production costs (reduction of conflicts, use of inputs, improvement of internal procedures, etc.). But the reports also show that certification had no direct impact on the income or profit of the large operators involved in certification. Neither has palm oil certification significantly increased the negotiating powers of smallholders, thus raising doubt as to its capacity to improve their share of the value added (Hidayat *et al.* 2016).

Regarding working conditions, Amnesty International (2016) shows evidence of forms of forced labour, unsafe working conditions and underemployment of wage-earning workers, even on certified oil palm plantations. This seems to confirm that the standards have brought few improvements in the labour conditions on plantations. Lastly, with respect to deforestation, a report by the Environmental Investigation Agency and Grassroots (2015) suggests that monitoring and auditing may be partial and biased: high conservation value forests as well as land conflicts are sometimes deliberately omitted from audits.

Regarding the ability of certification to reach a critical mass and make it possible to transform the industry in producing regions, it must be observed that not more than 50 per cent of certified palm oil has been sold as such since the beginning of the RSPO (i.e. the other half is sold as conventional oil even if produced with RSPO standards), and this proportion has not improved lately (see RSPO [2015, p.4]). Indeed, many downstream brand companies still remain below their RSPO certified procurement targets (WWF 2016). Moreover, some firms tend to turn to other sustainable procurement strategies that are not based on certification (see above section on campaigning and voluntary commitments). In particular, only one quarter of Nestlé's palm oil procurement is certified (WWF 2016, p.22), but the company has been very much involved in a traceability approach and a voluntary commitment to "No deforestation, No peat, No operation" in particular with the support of the organization The Forest Trust.

In addition, Indonesian and Malaysian governments recently voiced their concerns about letting Northern NGOs and private companies decide matters affecting the countries' sovereign development. They created their own "national" certifications, which they claimed would be more manageable. Such competing national certification schemes gained some modest adherence from businesses. However, from a consumer perspective, such schemes did not offer sufficient confidence for their claims to make their labels competitive with non-state approaches.

Box 9.3 Assessing certification's impact on Brazilian agriculture

Brazil is a key country in the production of tropical commodities and is a leader in certification of timber, coffee, sugarcane, cattle and soy. There are 69 types of standards, protocols and codes for sustainability applied to Brazilian agriculture with a wide range of sectors, crops, levels of assurance, impacts and transparency (ITC 2017). Some parts of these certification schemes cover goods up to final consumption while others offer attributes of quality or guarantees only for parts of the value chain. Learnings from implementation of certified eco-agri-food systems in Brazil are summarized here, based on experience with the Sustainable Agriculture Network (SAN)-Rainforest Alliance (involved with certifying coffee, cocoa, oranges, other fruits and cattle). In 2015 there were around 200,000 ha of SAN-Rainforest Alliance certified crops and animals on more than 500 farms in the country (Imaflora 2016), a miniscule though growing proportion of Brazil's agricultural sector.

Certified farms and forests are different and have higher net positive environmental and social performance than similar non-certified ones (Lima *et al.* 2009; Hardt *et al.* 2015). Pinto *et al.* (2014a) concluded that certification contributed to the conservation of natural vegetation and biodiversity in Brazil. Hardt *et al.* (2015) affirmed however that certified and non-certified coffee farms already showed such differences before the first audit occurred. The most important structural changes in fact occur on a farm when it prepares to be certified (Pinto *et al.* 2017). Despite this, Ferris *et al.* (2016) found that continuous improvement and progress of social and environmental performance occurs over time after initial certification, in both the short and long term. Progress is incremental, with fluctuations that include advances and setbacks as the performance of farms is influenced by external factors like prices of commodities, changes in climate and harvest, changes in leadership, among other external and internal factors.

Several authors (Ferris *et al.* 2016; Hardt *et al.* 2015; Campos 2016) showed that many certified farms are not in full conformity with legal requirements, ranging from basic workers' rights and guarantees (potable water, payment of salaries) to structural changes (forestry restoration, inadequate agronomic practices, needs for improvement in management and legal compliance). However, they had higher levels of compliance with other environmental and labour regulations than non-certified farms.

Pinto (2014) found that early adopters of certification were professional producers with large farms, high productivity, and high levels of technology and management in their business and operations. Later, some medium and small producers were attracted to SAN through group certifications, but they had previously been organized collectively, had high productivity and had received some form of outside support to achieve certification; other small and medium farms were unable to qualify for reasons listed below (Pinto *et al.* 2014b; Pinto and McDermott 2013).

In comparing the economic performance of certified and non-certified coffee farms, Bini *et al.* (2015) found that certified farms had higher productivity and revenues, a trend toward lower production costs, and had obtained similar prices for coffee sales to those of non-certified producers. Their higher profitability was thus derived from greater management efficiency rather than price premiums.

Despite this, it appears that the expectation of tangible economic benefits (especially in differentiated and over-priced markets) is the principal motivation for producers to seek certification, while investments needed for the changes required by certification, gaps in legal compliance and access to information are the main barriers identified by coffee producers to begin the certification process (Adshead 2015; Pinto *et al.* 2016).

Lessons derived from certification

Despite considerable uptake as a measure of change in eco-agri-food systems, certification has been severely criticized as a limited intervention in promoting sustainability. The present trend is to search "beyond certification". Such criticism comes from the expectation that standards and certification would stand alone, acting as a single solution to sustainability challenges in production systems, sectors and value chains. However, standards should be seen as part of a complementary mosaic of solutions (Pinto *et al.* 2016; Newton *et al.* 2014). Interventions become relevant when they reach a minimum level of implementation, sufficient to demonstrate the viability of a different or improved model of production and to influence decision and policy-makers in governments and companies. Although there is evidence that certification has contributed to transform value chains, the evidence suggests that it has not yet brought about large-scale territorial or landscape changes or caused structural changes in livelihoods across countries.

The future of certification as an instrument to support the transition toward eco-agri-food system sustainability depends on its attainment of greater impact at a landscape scale and connection and complementarity with other private and governmental initiatives to foment and induce sustainability. The fundamental debate is not about the potential to upscale certification itself, but how certification could contribute to the upscaling of sustainability. A move "beyond certification" should allow standards and certification to contribute more effectively to the upscaling of sustainability in the agriculture and food sectors. As a multi-pronged sustainability strategy, it should have synergies with other interventions aiming to eliminate predatory and illegal practices, including moratoria and other commitments and tools dedicated to stop deforestation, decrease emissions of greenhouse gases and eliminate slave and child labour. Other instruments worth mentioning are bounded or conditional credit, when farmers receive credits tied to environment-friendly management (Gross *et al.* 2016), and landscape (or jurisdictional) approaches where the sustainability of production is managed at the scale of a territory, based on a co-operation between local governments, businesses and NGOs (Aubert *et al.* 2017b). However, stakeholders should be cautious and aware that measures directed toward improvements along these lines should both interact with and complement high performance standards. More research is needed to understand better how compliance costs could be reduced and effectiveness of sustainable practices enhanced.

If urgent and short-term interventions are needed to eliminate the worst practices in the agri-food system, other medium and long-term solutions and tools are needed to foster the best. Any intervention (like certification) may reach a tipping point when its essential logic infiltrates a sector or value chain. A tipping point is reached with certification when the collective actions necessary to meet standards become an integral part of the policy, research, supportive institutions and resources, etc., of mainstream decision makers involved in this sector, be they private or public. For instance, a tipping point for coffee, cocoa, tea, and palm oil has been reached, but not for sugarcane, soya or cattle. For the former, every event, company policy and research agenda includes certification as a subject. Therefore, the certification frame has highly influenced the entire agenda for the sector. The TEEBAgriFood theory of change implies engaging a critical mass of firms so that revealing hidden costs becomes a standard for reporting and adjustment. A TEEB assessment would serve as a basis for benchmarking and competitive advantage in the relevant food segment, a standard of business performance.

9.4.3 Multilateral Agreements and science-policy interface processes[4]

A host of multilateral agreements and agendas in force or under negotiation represent strategic opportunities for the exposure of hidden costs in the food system, and means to address them through policies and trade measures. Among the most significant are the global framework conventions on climate and biodiversity, and their respective implementing instruments related to reduction in emissions, equitable benefits sharing and intellectual property rights. These concerns interact with a wide realm of multilateral accords addressing trade, development and finance, which are pertinent to food system governance. However, the scope of this section will limit itself to environmental agreements and related agricultural policy measures.

These agreements aim to meet their objectives by promoting good land use and forestry practices and encouraging resource conservation.[5] The results, such as those obtained through the differential incentive approach incorporated in the European agro-environmental measures under the Common Agricultural Policy (CAP), show that protection of multifunctional natural landscapes on private farmlands has been uneven and in many areas the program is undersubscribed. Complementary measures sensitive to national, global and local contexts may be essential to achieve the goals of multilateral agreements (Santos *et al.* 2015). TEEBAgriFood can promote greater knowledge of the additional offsite benefits that arise from good practices on the farm field, practices that should be more adequately remunerated through policy and markets. This in turn reinforces the need for interdisciplinary thinking across silos to coordinate disparate objectives.

More and more, the adoption of multilateral agreements on complex themes has been accomplished through processes subject to voluntary agreement and periodic review rather than rigid controls or sanctions (see Chapter 10). The growing complexity of such agreements requires integrated thinking, institutional learning and innovation. This context of voluntary undertakings makes TEEBAgriFood especially useful in identifying trade-offs and values associated with alternative actionable agendas. On the other hand, it is important to recognize the critical role played by major actors in the food system whether in resisting or directing the need for change, as emphasized throughout this chapter. For this reason, it is essential for TEEBAgriFood to seek allies among such actors and across the spectrum of concerned players in the food system to shape voluntary agreements.

As a strategic means of introducing the approaches embodied in the TEEBAgriFood Framework to multilateral decision-making, this report (see Chapter 10) proposes a specific focus on the implementation of the Sustainable Development Goals (SDGs) and the 2030 Agenda. Both relate to a host of concerns pertinent to change in food systems globally, as well as the interaction between eco-agri-food sectorial goals and human wellbeing, particularly poverty alleviation, health, and human rights, including the right to food. For TEEBAgriFood to fulfil its promise at the level of multilateral agreements implies a theory of change that can only be satisfied through innovative (“out of the box”) thinking, knowledge sharing and institutional learning by all actors engaged in their negotiation, factors also critical to progress toward the SDGs.

Tension at the multilateral level often arises due to the nature of competitive global markets and concern for national sovereignty. Successful efforts to combat externalities require coordination and cooperation among actors, as discussed under Section 3.1. Progress in negotiating such measures can falter when States perceive that national sovereignty over their developmental destinies is being undermined. For example, barriers to concerted action on deforestation in many countries were overcome by debate among actors in successive conferences of the parties to the UNFCCC. Stakeholder engagement to identify cross-sectorial policy factors affecting observable change in land use behaviour led to greater impact of REDD+ measures (measures aimed at reducing emissions from deforestation and forest degradation) and improved the coordination of associated policy instruments (Young and Bird 2015; Sills *et al.* 2015). This experience gives additional credence to a theory of change vested in conciliation among stakeholders to achieve consensus on complex problems. It is important to be clear, however, that consensus is not always possible without dilution of policy goals. Thus, it is necessary to make explicit the reasons for reluctance by key actors and to negotiate means to override their resistance (e.g., through conditions or compensation).

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[4] This section is keyed to further discussion that is the focus of implementation of such accords and TEEBAgriFood’s role in this, in Chapter 10.

[5] These include, inter alia, the dictates of the UNFCCC related to reduced emissions from deforestation and degradation (REDD+), and the Aichi targets for implementation of the Convention on Biodiversity relative to conservation in the productive landscape and degraded land restoration.

The effectiveness of global accords as they translate to policy and transformational practices on the ground is often far more complex to trace. One notable exception relates to the gradual improvement in the regulations surrounding the UNFCCC Clean Development Mechanism (CDM) and later REDD+ to enable "jurisdictional" interventions among groups of smaller scale projects. This change, responding to concerns for equitable access by small and medium enterprises, overcame barriers to entry arising from the high transactions costs of CDM initiatives whose timeline from approving baselines through implementation often took years. The flexibility imparted to the CDM resembles similar openings that have arisen out of other global agreements (e.g. rewarding traditional people for their knowledge of agrobiodiversity or territorial protection of carbon stocks by indigenous peoples). Their relative success in influencing negotiators and gatekeepers in the global accord and associated grant funding institutions has been a function of the effective mobilization of target groups along with the support of international advocacy and epistemic communities. Allies within national governments and international NGOs have also played key roles in bringing about such strategic change.

Food systems are the subject of considerable discussion among a plethora of science-policy interface (SPI) initiatives. Bringing global actors together around common objectives often implies the need to bridge different knowledge, value and belief systems. The relevance of SPI results depends on their utility in addressing policy problems. Generating and communicating scientific knowledge alone is insufficient to make significant progress on sustainability (Turnhout *et al.* 2012).

A case in point is that of a recently released assessment of pollinators, pollination and food production (IPBES 2016). This assessment benefitted from feedback obtained from regional producer organizations and beekeepers who mapped the occurrence of pollination deficits in agricultural crops, pinpointing possible sources of damage to pollinator populations such as excessive pesticide application. Such assessments have the potential to achieve considerable influence over concerned groups and may contribute to societal recognition of the problem, so affecting regulatory decisions (Pascual *et al.* 2017). However, it is our contention such an assessment would be more effective if completed with the contributions of the TEEBAgriFood Framework, which allow an accounting of the indirect drivers of biodiversity and ecosystem service loss including harmful subsidies and other factors promoting unsustainable agriculture (Rankovic *et al.* 2016), and hidden costs faced by society for such losses, as in the case of the pollination deficit.

9.4.4 Instruments to change Government and overseas assistance policy

In practical terms, beyond the TEEBAgriFood Evaluation Framework, the accompanying assessment of the costs of policy inaction has proven highly effective in asserting the need for reshaping policies and intergovernmental cooperation at different levels. The assessment of the enormous costs in infrastructure and crop productivity associated with predicted losses of ecosystem services and terrestrial sinks helped to spur greater investment in needed research and policy action. Here too, the evaluation of consequences of such change requires interdisciplinary thinking and consultation among stakeholders to map plausible scenarios and to imagine the effects of specific interventions, consistent with the TEEBAgriFood theory of change. It should be noted that a recent consultation of agribusiness and food industry companies indicates that a lack of complementary government actions was a major constraint for their effective participation in multi-stakeholder landscape partnerships (Scherr *et al.* 2017).

TEEBAgriFood has potential to add considerable value to the arena of public finance and international development cooperation, where the consequences of unsustainable paths of expansion in food systems are in dire need of better assessment. This became clear even in the initial stage of TEEBAgriFood, where the focal were accompanied by obvious and significant externalities along their value chains. The results of the Addis Ababa Action Agenda indicate the need to provide greater support toward public-private partnerships in strategic areas of investment for development assistance, including infrastructure and technology. The sustainability goals articulated the same year by the United Nations could similarly leverage TEEBAgriFood's influence to a wide scope of both public policy and private sector endeavours. As one example of governmental fiscal measures compatible with the Agenda, taxation on sweetened beverages as an instrument to motivate change in consumer behaviour to promote healthier diets has been adopted on a trial basis in localities in both the US and Mexico (see **Box 9.4**). At the national level, the case of pesticide taxation adopted in Thailand discussed in Chapter 8 offers a similar perspective. On the other hand, although taxes can reduce consumption and raise revenues that can be channelled to combat externalities, subsidies and other incentives can distort and create excess demand.

Box 9.4 Experience with taxation on sweetened beverages

The causal link between ubiquitous use of maize-based sweeteners and public health costs due to growing rates of obesity has been made effectively by lawmakers in the US and Mexico, resulting in the adoption of soft drink taxes to depress demand. The effects of these taxes, passed initially by voters in Berkeley, California was traced to a 21 per cent drop in soft drink consumption four months after the measure was adopted. A parallel study in Mexico found a 17 per cent drop in consumption of such beverages among low-income households after a one peso per litre tax was adopted on soft drinks in 2013 (Sanger-Katz 2016). “Such levies have been enacted in 30 countries, including India, Saudi Arabia, South Africa, Thailand, Britain and Brunei. More than a billion people now live in places where such taxes have driven up the price of sugar-sweetened beverages”, illustrating the potential importance of economic incentives on consumer behaviour (Jacobs and Richtel 2017). Such effects can be even more pronounced if coupled with information for consumers regarding nutritional and health benefits of restricted soft drink consumption.

TEEBAgriFood has the potential to reshape rural-urban economic and ecological relationships by influencing urban and regional government officials recently exposed to agriculture and food security narratives, who are conceivably more open to test new models (Forster and Escudero 2014).

9.4.5 Influencing financial sector roles in the food system

The finance sector is increasingly aware that environmental and social dependencies of their clients and investees increase the sector’s risk exposure. Examples include situations in which clients are unable to fulfil financial obligations due to disruptions in natural capital service provision (water, pollination, etc.) or when financial institutions experience losses of asset values due to environmental impacts. Finance institutions are progressing in the assessment of these impacts and dependencies in order to reduce their risk exposure and to direct their lending, investment and insurance services towards activities with lower impacts and dependencies on natural and social capital.

These processes have garnered greater significance with the issuance of the Addis Ababa Action Agenda (AAAA) on sustainable finance, under whose rubric a number of commitments have been made to address both public and private sector investment for development. TEEBAgriFood has identified the AAAA as an important opportunity for indicating key areas for investment in critical nodes of food systems, and to sensitize such investment to the need to conserve natural capital stocks (see Chapter 10).

The Equator Principles is a framework adopted by major finance sector institutions to introduce environmental and social criteria into their lending decisions. The Equator Principles provide a minimum standard for due diligence to support responsible risk decision-making (Equator Principles 2013). This frame is used to evaluate major infrastructure and industrial projects, with a capital cost over US$ 10 million. Borrowers unable to comply with the social and environmental policies and procedures of the finance lender are denied access to funds. As of 2017, 91 financial institutions representing 70 per cent of international Project Finance debt in emerging markets had signed on to the Equator Principles. The Equator Principles still fall short in ensuring financial sector accountability (WWF 2006; Wörsdörfer 2013). The TEEBAgriFood Framework can improve the accountability of lending projects related to the agribusiness sector by making visible the external costs of such investments.

A growing appetite for sustainability investing is leading to increasing demand for information to support decision-making (Macpherson and Ulrich 2017). The use of sustainable financial market indicators, such as the Dow Jones Sustainability Indices, provide information on incorporation of environmental, social and governance criteria (ESG) by large companies[6] at the global level. Other initiatives on disclosure of sustainable information include the Carbon Disclosure Project (CDP), which informs investors how investee entities manage their climate and water impacts. Similarly, the Recommendations of the Task Force on Climate Related Financial Disclosure (TCFD 2017) provide guidance for voluntary and consistent climate-related financial risk disclosure by companies to better inform financial institutions and other stakeholders. In this context of growing interest, the TEEBAgriFood Framework can contribute by providing a framework for valuation and evaluation of environmental and social aspects to help agribusiness companies provide more complete information to investors as well as enable investors to identify key concerns to guide their investment decisions.

Apart of these disclosure initiatives and frames for risk assessment in project finance, the assessment by the finance sector of natural capital risk and opportunity is currently highly focused on water risk exposure and

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[6] In 2016, 3400 companies were invited to participate on the Corporate Sustainability assessment to elaborate the Indices.

climate change, both closely related to the agribusiness sector. Some examples of tools used by the finance sector for the assessment of natural capital risk and dependencies are water resilience assessment tools developed by the Natural Capital Finance Alliance (NCFA)[7]. The finance sector has made progress on the assessment of water and climate risks but there is a need for a more comprehensive understanding of the relations between the finance sector and natural capital. The Finance Sector Supplement to the Natural Capital Protocol[8] is intended to fill this gap and provide a more robust and holistic view regarding natural capital to financial institutions. The contributions of the Supplement compared to other existing approaches consists of:

- Broadening the scope of assessment by including both impacts as well as dependencies on natural capital of clients and investees;
- Promoting the measurement of impact drivers and dependencies but also their valuation from a financial and/or societal point of view; and
- Analysing natural capital in a more systemic way, moving from an analysis of impacts on climate and water alone to a more holistic and integrated view that integrates a broader range of interconnected aspects (including biodiversity, soil, water quality, etc.).

A draft version of the Finance Sector Supplement was published in May 2017 (Natural Capital Coalition 2017). After a consultation and piloting phase, a final version of the Supplement will be published at the beginning of 2018. The Finance Sector Supplement and the TEEBAgriFood Framework are closely aligned. TEEBAgriFood is written for a broader audience, but it will provide complementary insights on the assessment of social impacts (health, equity, etc.) and dependencies enabling the inclusion of social capital into the assessment of agribusiness companies by financial institutions. There may also be potential by coalitions of investors and local stakeholders to recruit and coordinate investments to influence food systems in particular geographies, including actions on farms, ecological connectivity, natural and built infrastructure, supporting certification, reforestation and grassland restoration, soil restoration, etc.

9.4.6 Instruments for sustainable eco-agri-food business practice

Two of the five major external costs identified by Trucost (2013) at global level are generated by the eco-agri-food sector, namely: land use change due to cattle ranching and farming in South America and water consumption due to wheat farming in Southern Asia. Agriculture and seafood are among the economic sectors that pose the greatest threat to critical ecosystems through impacts such as soil erosion, air, land and water pollution, deforestation of habitats and species reduction (WWF 2012).

The eco-agri-food sector not only impacts on natural capital but also depends on it. Deeply embedded within ecosystems, the eco-agri-food sector creates a strong dependency for access to raw materials, energy, land, water, and a stable climate. Biodiversity is also critical to the health and stability of natural capital, and to essential flows of ecosystem services for the eco-agri-food sector, as it underlies resilience to floods and droughts, provides pollination services, and supports carbon and water cycles, as well as soil formation (Natural Capital Coalition 2016). Ecosystem services are critical not only to rural communities but also to urban and rural enterprise including tourism, infrastructure such as hydroelectric generation, water supply and irrigation, In particular, environmental degradation poses a direct and critical threat to the agribusiness sector: as much as US$ 11.2 trillion in agricultural assets could be lost annually as a consequence of environmental risks including climate change and water scarcity (Caldecott *et al.* 2013). Conversely, well-managed natural capital can provide positive opportunities. The Business and Sustainable Development Commission sets the economic value of a transformation to sustainability of the global food and agriculture system at “more than US$2 trillion by 2030” (BSDC 2017).

The information and knowledge provided by researchers, academics, NGOs and others provides an evidence base for the consequences of natural and social impacts and dependencies on agri-food businesses. Such evidence is driving change among many key actors: businesses are realizing that the availability and quality of natural capital can impact the demand for and cost of raw materials, energy and water; businesses are also realizing that their natural capital impacts and consequences on society can affect their license to operate, staff retention rates, etc.; governments are reinforcing legal frameworks for natural resource and social protection, consumers are increasingly demanding more social and environmentally respectful products, finance institutions are integrating environmental, social and governance criteria in their investment decisions and assessing climate and water risks on their practices. It is time for agri-food businesses to foresee and to manage the potential risks and opportunities. The internationalisation process has

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[7] The Natural Capital Finance Alliance has developed two tools for water risk assessment: (i) Drought Stress Testing Tool for Banks that helps banks understanding risk of loan default driven by droughts and (ii) Corporate Bond Water Credit Risk Assessment Tool, which provides investors with a systematic and practical approach to assess water risk in corporate bonds and benchmark companies against sector peers.

[8] The Finance Sector Supplement to the Natural Capital Protocol is developed by a consortium composed of the Natural Capital Coalition, the Natural Capital Finance Alliance and the Dutch Association for Sustainable Investment (VBDO).

increased competition in global markets and some farmers and agribusinesses are already integrating natural capital into their decision-making. Other companies will need to properly manage their natural and social capital risks and seize their opportunities to be able to succeed in the long term.

Up to 2030, the global agenda is going to be driven by the Sustainable Development Goals (SDGs) adopted in September 2015. Business has a significant role to play in achieving these Goals. The SDGs articulate how business and economic success depend on, and are innately connected to, social and environmental success. Businesses need to use a structured approach to measuring their contribution to the SDGs, by understanding and assessing how dependent they are on capitals (natural and social); and what impacts they are having on them. These two questions will have to be faced by all stakeholders (governments, businesses, associations and individuals) and not only in relation to natural capital but also to social and other types of capital, as the SDGs are indivisible. The capitals approach, and the Natural Capital Protocol, not only allow organizations to ask themselves these questions, but provide a pathway to the answers by supplying a standardized framework to identify, measure and value impacts and dependencies on the capitals, bringing them into the decision-making process, and working with other actors to deliver on the SDGs.

In the remainder of this section, actions proposed by the Natural Capital Coalition for companies are described in terms of their operational, legal, financial and reputational liabilities, as well supply chain traceability, integrated landscape management and agroecological zoning.

Publication of a Food and Beverage Sector Guide has assisted implementation of the Natural Capital Protocol by providing additional guidance and sector-specific business insights, including: context on why natural capital is relevant to businesses and how they benefit from it; the business case for natural capital assessments; identification of natural capital impacts and dependencies relevant to the sector; and practical sector-specific business applications of the Protocol framework.

Some concrete examples in the Guide include: significant cost increases to protect fast moving consumer goods companies from increases in food prices; dramatic water costs increase (300 per cent) for food manufacturers in countries under water scarcity; and drops in share prices of companies due to key raw materials price rises. On the other hand, other cases show existing opportunities such as the growing organic food market or savings from adoption of circular economy and renewable energy approaches in food processing.

The Food and Beverage Sector Guide shows the business implications of different risks and opportunities experienced by the sector. These risks and opportunities are described below while some real-world examples are shown in **Table 9.1**:

1. Operational: when the availability and quality of natural capital can impact the demand for or cost of raw materials, energy and water.

2. Legal and regulatory: regulation and legal action can restrict access to resources, increase costs, and influence options to build or expand.

3. Financial: Financial institutions are increasingly introducing sustainability criteria to inform decision-making and driving value.

4. Reputational and marketing: Changing consumer preferences can influence sales and market share.

5. Societal: Relationships with the wider community may be positively or negatively influenced due to activities impacting local natural resources.

Table 9.1 Real-world examples of well managed natural capital risks and opportunities reflecting distinct stages in the value chain

Risk and opportunities category	Stage of the value chain	Example of natural capital risk and opportunities managed
Operational	Agribusiness	As response to a 15 per cent almond yield reduction in California, Olam developed a drought response action plan to explore alternative practices. By broadening its outlook on soil dynamics (enhancing water holding capacity and soil nutrition), Olam thus reduced its dependency on an ever more pressured water resource (Cranston *et al.* 2015). The apparel company Kering is developing Environmental Profit and Loss accounts to identify key natural risks and opportunities and provide them with trustworthy information for decision-making. Based on their accounts, Kering decided, for example, to replace conventional cotton supplies by organic cotton when they realized that water consumption for organic cotton is three times lower than that required by conventional practices.[9]
Legal and regulatory	Agribusiness	The EU agro-environmental measures adopted under the Common Agriculture Policy (CAP); ecological-economic zoning (see **Box 5** on sugarcane in Brazil) and credit earmarking for sustainable practices create opportunities for innovative enterprises. Water scarcity, exacerbated by climate change, could cost some regions up to 6 per cent of their GDP in the future. When governments respond to water shortages by boosting efficiency and allocating even 25 per cent of water to more highly-valued uses, such as more efficient agricultural practices, losses decline dramatically and for some regions may even vanish (World Bank 2016).
Financial	Agribusiness	Several agribusiness projects acceded to IFC green bonds (IFC 2016).
	Food and beverage industry	YES Bank assessed the impacts and dependencies of the food and beverage sector through a case study, showing that the real value of water is 18 times the current industrial water rate in an Indian province (Dangi and Shejwal 2017).
Reputational and marketing	Agribusiness	Land area under organic agriculture worldwide tripled from 1999 to 2012 (FiBL 2014)
	Food and beverage industry	Eosta, an international SME distributor of fresh organic and fair-trade fruits and vegetables, developed an integrated profit and loss account to communicate their true value creation compared to a non-organic trading company (Eosta *et al.* 2017).
Societal	Agribusiness	A cooperative program among agricultural community and wildlife interests resulted in enhanced soil quality, increased biodiversity, and maintenance of valuable agriculture and waterfowl habitat in British Columbia (Canada) as the result of an initiative of Delta Farmland & Wildlife Trust (Zhang 2017). NESPRESSO sources 82 per cent of its coffee through the Nespresso AAA Sustainable Quality™ Program, which supports farmers in their efforts to achieve compliance with certification standards (Nespresso n.d.).

The Food and Beverage Sector Guide to the Natural Capital Protocol framework is intended to provide business with a better understanding of the changes in natural capital derived from their activities (not only their operations, but also upstream and/or downstream), and to estimate the value of those changes for the business and/or for the society. The framework provides agribusiness with a holistic view of natural capital, by understanding it as a system rather than focusing on independent aspects. The frame is intended to provide agribusiness companies with trustworthy and actionable information to support their decision-making processes. The Protocol and Sector Guides were piloted and tested by group of companies, whose feedback contributed to enhance the applicability and usefulness of the framework. Within the pilot testers group, there was a good representation of companies from the agribusiness sector: 20 per cent of the fifty companies that participated in the pilot phase were directly connected with the agribusiness sector (including Olam, Nestle, Nespresso and Marks & Spencer, as described in **Table 9.1**).

Some of these large companies pioneering the integration of natural capital into decision-making are also influencing the whole sector through their supply chain, including small and medium agribusiness companies. This is the case of manufactures or retailers introducing sustainability requirements for purchasing products, for example the Unilever Sustainable Palm Sourcing Policy that sets a target of using 100 per cent of certified palm oil by 2019 (Unilever 2016). However, as discussed in Section 2 with reference to palm oil, certification has not always been successful in changing the status of an industry as a whole. Other instruments, such as agroecological zoning, may be more effective in combination with certification (see **Box 9.5**).

Companies do not only need to integrate natural capital but also social and human capital into their decision-making, for instance, by looking at the benefits of investing in women's empowerment across value chains (Jenkins *et al.* 2013; BSR *et al.* 2016). The Food and Beverage Sector Guide provides a frame for natural capital assessment. The TEEBAgriFood Framework expands this scope by providing a comprehensive frame to integrate all capitals: economic, environmental, social and human capitals, all of which must be measured and valued in order to properly assess the exposure of farmers and agribusiness to potential risks, as well as identify potential opportunities. Adopting practices that account for all such factors will increase sustainability of their business models in the long term. There is a perceptible increase in attention and proliferation of such collaborative initiatives for the business sector. Business-centred multi-stakeholder platforms form an integral part of TEEBAgriFood's proposed engagement strategies and will be discussed in greater depth in Chapter 10 of this report.

A further area for business engagement, Integrated Landscape Management (ILM), provides a growing role for business cooperation in assessment of external costs. Collaboration between ILM initiatives and agribusiness and food industry companies include corporate sustainability commitments and responses to growing local business risks of natural resource degradation, climate change and community relations in their operations and sourcing regions. Specific lines and cases of such experience of business engagement in ILM are explored in detail in Scherr *et al.* (2017).

The case of sugarcane zoning in São Paulo, Brazil, described in **Box 9.5**, represents one experience at a subnational level to conserve and restore critical land and water resources and avert health hazards. In this case, a coalition of agribusiness organizations, government and scientific research institutions has collaborated in assessing the risks of policy inaction and designing appropriate interventions. Nevertheless, it is important to avoid the tendency to focus on a single commodity, and adopt a multi-commodity approach within interventions targeting a specific landscape or region.

Box 9.5 Zoning of sugarcane expansion in Brazil

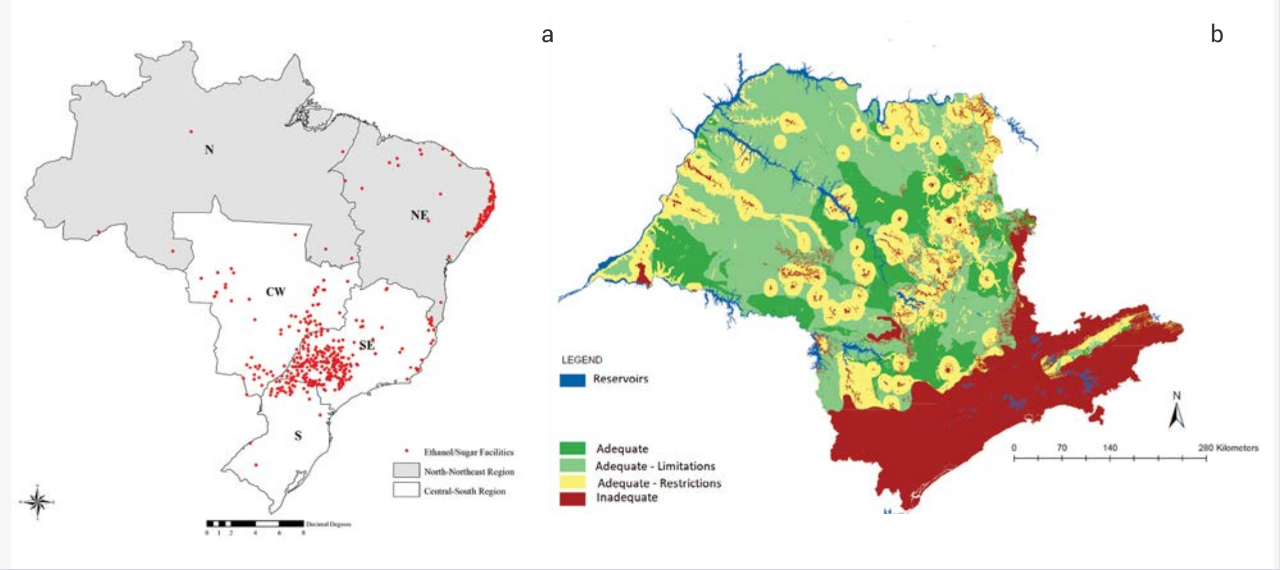
The growth in demand for both sugar and ethanol in recent years has resulted in expansion of sugarcane production and concerns expressed by both domestic and international actors regarding the negative impacts of land-use change (LUC) in Brazil, including greenhouse gas emissions, biodiversity loss, and impacts on food security.

The most extensive Brazilian sugarcane plantations are found in São Paulo, which produces nearly 60 per cent of total output. Government in the 2000s vigorously promoted Brazil's sugar-cane ethanol abroad as a clean fuel from a renewable source, able to deliver substantial GHG emission reductions by displacing fossil based fuels (UNICA n.d.; Wilkinson and Herrera 2008; WWF Brasil 2008; Egeskog *et al.* 2014). Occupying former pastures and some cropland, (Adami *et al.* 2012) sugarcane became a dominant element of the landscape (see **Figure 9.5a**).

Use of sugarcane for both ethanol and sugar production complemented and fortified the agro-industrial complex. The domestic market for gasohol and ethanol-fuelled vehicles expanded rapidly in the 1970s under federal incentives, and was later driven by the spectacular growth in flex-fuelled vehicles. Investments directed at the Brazilian sugarcane sector grew rapidly.

Inhumane working conditions have long been associated with sugarcane cutting (Wilkinson and Herrera 2008; Repórter Brasil 2009) – as well as concerns related to deforestation. Impacts caused by sugarcane plantations include deleterious effects on water resources, biodiversity, soil, air quality and socio-economic conditions. Impacts of land use change include water pollution, soil degradation, application of pesticides and fertilizers, pressures on other crops and native forestland, as well as GHG emissions and particulate matter pollution from sugarcane burning (Coelho *et al.* 2007; Coelho *et al.* 2011; Goldemberg *et al.* 2008; Martinelli and Filoso 2008; WWF Brasil 2008).

Figure 9.5 a. Location of sugarcane processing units in Brazil (Source: Walter *et al.* 2014). b. Agro-environmental Zoning of Sugarcane Industry in São Paulo (Source: SMA 2009)



Environmental quality impacts led to the negotiation among stakeholders to adopt policies that go beyond that mandated by national law, seeking to limit sugarcane expansion to areas whose resilience to such conversion is greater, and to work along the entire sugarcane value chain toward an integrated production system (Nassar *et al.* 2008; Nassar *et al.* 2011). The adoption of a sugarcane zoning protocol addressed diverse concerns.

In the late 2000s, the state of São Paulo undertook a strategic environmental project called "Green Ethanol" in partnership between the state secretariats of environment and agriculture and the Brazilian Sugarcane Industry Association (UNICA), resulting in the creation of an Agro-environmental Protocol and Agro-environmental Zoning Plan (SMA 2009). This initiative, based on an understanding between government, sugar mills and suppliers, sought to organize sugarcane-based agro-industrial activity to promote environmental compliance and minimize impacts.

The Agro-environmental Protocol was published in 2007, as a morally binding voluntary commitment (see further discussion on "pledge and review" processes in Ch. 10). The Protocol covers the following measures for impact reduction in sugarcane plantation: (i) anticipate legal deadlines for phasing out sugarcane burning, prior to harvesting, (ii) protect and recover riparian forests and springs on sugarcane farms, (iii) reduce water consumption, (iv) establish proper management of agrochemicals and (vi) encourage air pollution and solid waste reduction in industrial processes. Despite the high investment costs conveyed by the Protocol's requirements, significant gains in productivity are predicted (Coelho *et al.* 2011). Adoption of these practices is promoted as an investment with a positive return due to improved terms of market access and risk protection (TNC n.d.). As a result of the adoption of such measures, production plants receive a "Green Ethanol Certificate" of compliance (UNICA 2010; Coelho *et al.* 2011; Imaflora 2015).

The Green Ethanol program also introduced Agro-Environmental Zoning (ZAA), launched in 2008. The ZAA was designed to direct the expansion of sugarcane into new production areas, identifying restrictions for production, including protected areas and biodiversity conservation concerns, soil and climate aptitude, air quality, water availability and topography (SMA 2009). This exercise culminated in the publication of a zoning map, which categorizes land suitability for sugarcane cultivation and for establishment of agro-industrial facilities (Figure 9.5b). Although these regulations do not empower authorities to deny activities non-compliant with the zoning map, public development banks, international agencies and external investors may condition finance on meeting zoning criteria (see Section 9.4.5).

Barriers to successful application of the protocol include the employment of new equipment and coping with labour dislocation due to mechanization, while demand is unfulfilled for more skilled workers. Proper monitoring and inspection of policies and instruments and their effectiveness in protecting against impacts on labour and fragile biota are needed. A full valuation of the externalities associated with sugarcane expansion highlighting their various hidden costs would represent an important opportunity to bolster policy decisions. This would entail identifying the local as well as global benefits associated with adherence to the Green Protocol and zoning, while reinforcing its effectiveness through dissemination to stakeholders of the sucra-alcohol complex beyond São Paulo where sugarcane cultivation is undergoing rapid expansion in the Center-West region of Brazil.

9.4.7 Instruments to guide Farmers' practices

Innovations are adopted depending on a "recipient" agent's propensity to adopt or to resist technical change (Rogers 1995). Early adopters lead by example, encouraging others to take up innovations or be expelled from the market due to inability to adopt before being "creatively destroyed" (Schumpeter 1974). In our view, however, the "laggards" (who exhibit strategies of risk aversion and precaution), rather than being a drag on the system, are in fact those who TEEBAgriFood should seek out in order to protect them from the effects of conventional agri-food innovations, including the damages these forces can bring to the environment, human health and welfare of rural communities.

A more effective and inclusive approach to innovation would rely on a bottom-up approach to technology development and improvement, starting with farmers' own natural propensity to experiment and learn how to adapt tools and germplasm to their specific context. Upstream scientists who experiment with controlled variables primarily on research stations, usually with a focus on marginal lands and limited resource farm communities, have struggled to integrate such ideas into mainstream agricultural research procedures. This began with the Farming Systems Research (FSR) strategies of the 1980s, which were a reaction to Green Revolution failures to adequately address issues related to rain-fed, upland or dryland hardscrabble dirt farmers.

FSR involves participatory diagnosis with farmers, looking at their cultivation, livestock integration and intercropping or agroforestry systems. The next steps are on-farm trials of incremental modifications in the hope of reducing limitations to resilience and stabilizing the use of existing resources (Collinson 2000). Though FSR had some notable successes, it was outmanoeuvred by the strong economic interests that benefit from the current system (chemical, seed, tractor companies, etc.) and which have access to government through their respective lobbies; there are few comparable dedicated groups with strong enough economic interests to maintain support for FSR. There remains, in consequence, very little international or domestic investment in FSR or alternative production systems such as organic, agroecological, agroforestry, etc. relative to conventional systems.

Despite the failure of FSR and similar approaches, one of the notable recent CGIAR (formerly the Consultative Group for International Agricultural Research) ventures into this terrain is AR4D (Agricultural Research for Development) whose notable work on a multitude of sub-programs within the scope of the CCAFS (CGIAR Program on Climate

Change, Agriculture and Food Security) adopts a Theory of Change perspective akin to that of TEEBAgriFood as a starting point (Thornton *et al.* 2017):

> *CCAFS's approach to theory of change is centred on adaptive management, regular communications between program and projects, and facilitated learning within and between projects.... Many project participants and partners were willing to take on the challenge to develop new ways of collaborating and working beyond delivering outputs. After one year of the pilot phase, several projects had made considerable progress, although making fundamental shifts in the way of working takes time and (initially at least) additional resources, as well as iteration and learning. It also may affect team composition. Some projects recognised that additional skills beyond disciplinary expertise would be required, such as skills in coordination, facilitation, engagement, communications, and participatory a learning-oriented monitoring and evaluation. Stakeholder buy-in and a supportive organisational environment were also seen by most projects as necessary elements in implementing the approach.* (Thornton *et al.* 2017, p.148)

This polycentric, multi-stakeholder approach that takes into account shared learning as a basis for attaining results has much in common with the TEEBAgriFood Theory of Change.

To incentivize the adoption of best practices by farmers, PES schemes (payment for ecosystem services) have begun making the link between downstream users and upstream producers, particularly for water quality and flow regulation. For example, in Mexico, Ecuador and Costa Rica, national programs for PES have been underway for over a decade. Although hotly debated in the literature with respect to their effectiveness and equitable distribution of benefits (Muradian *et al.* 2013), there is no question that the appeal is greater for rewarding those who do good for the environment than fining farmers for doing the wrong thing. Numerous PES models have been developed that accelerate conversion to good management practices and natural area management, at relatively low cost. The major challenge is organization, and mobilizing finance for farm/landscape investment before ecosystem service flows are realized. A decisive role for TEEBAgriFood assessment in this respect would be to furnish information that would support effective early targeting of compensatory payments to farmers who agree voluntarily to participate in PES programs.

As indicated earlier in this section, fair trade practices and certification in some commodity areas have brought some improvement in the share of value added that accrues to farmers. It is nevertheless true that the lion's share of the benefits from the rising consumer concern for food quality and origin falls to intermediaries and retailers. TEEBAgriFood can provide tools to help family farmers and smaller actors better negotiate such arrangements. One way to do this is to influence procurement policies for institutional food provision by government, business and schools. In Brazil, for example, agreements between local governments and farmers subsidized by federal price supports stipulates that ingredients for school lunches be provided through specific arrangements and a goal that 30 per cent of all such supplies be provided from local sources.

Finally, levers are needed to motivate large farmers in industrialized countries to adhere to sustainable production standards, a significant challenge. Policy signals are gradually leading large-scale food producers and processors to respond to health concerns. To supply the growing demand for organic, locally sourced or fair-trade foods, such goods must now be grown at a larger scale. Yet the market for organic food in the US was still only 5 per cent of all home-consumed foods in 2015, though this share had doubled since 2005 (Greene *et al.* 2017). And certainly, the broader market is also reflecting concerns of society, as discussed below.

In countries where large-scale commercial agriculture has been a source of environmental problems, confrontations have arisen between farmers/agribusiness and environmental organizations. Farmers often view environmental rules as a tool of social control by groups antagonistic to the difficulties they face. Finding more collaborative models that empower local actor groups to negotiate and devise solutions to achieve those goals may be much more effective than setting specific field or farm-level rules that do not fit the local context.

In developing countries there is still a widespread lack of support to enable transition at scale to more sustainable agricultural systems. In many countries conventional agricultural supporters point to a track record of how increased fertilizer supply benefits yield and offer advice on how to effectively distribute fertilizer to the field; such a solution is not in place for inputs or products of alternative farming systems. The metrics to illustrate the costs and benefits of proposed improvements in value chains in this context are elusive.

9.4.8 Tools to change Consumer behaviour

Consumer concerns are proximate, myopic and personal; the material effects of food on one's health, satisfaction, and wallet are major immediate influences. Information on packaging and the sensitivity toward medical suggestion are important sources of influence to drive change in consumer behaviour. Recent surveys by Nielsen (2016) show that there has been a significant change in consumer attitudes toward the healthiness of foods available to them, which will undoubtedly shape the direction of things to come in eco-agri-food systems. These include:

- More than one-third (36 per cent) of 30,000 global online survey respondents in 66 countries say they have an allergy or intolerance to one or more foods;
- Nearly two-thirds of global respondents (64 per cent) say they follow a diet that limits or prohibits consumption of some foods or ingredients (particularly in Africa/Middle East and Asia) – nearly half of these do not feel they are being adequately served by food available to them;
- More than half of consumers say they're avoiding artificial ingredients, hormones or antibiotics, genetically modified organisms (GMOs) and bisphenol A (BPA).

Unfortunately, there is a class divide in food awareness that limits the breadth of these more positive impacts of consumer concern. Healthy attributes are credence goods, that is, their purported qualities cannot be easily verified directly by consumers (at least not immediately on purchase or consumption). Consequently, the process of consumer decision-making is largely influenced by the level and quality of information she possesses, and which is supplied by the market. Manipulation of such information to provide a healthy image to consumers is common. To build a stronger consumer awareness of the characteristics and quality of foods, to enable more discriminatory choices is thus a major priority to promote change in the eco-agri-food system. This is an even greater challenge when the most precarious dietary conditions are found among the poor, who – even in the richest countries – are more susceptible to nutrition-related maladies such as obesity and diabetes.

Communication strategies that engage a wider audience on food and health and show linkages to social and environmental issues are a tool for informing and influencing consumer behaviour. In Chapter 10, a proposal for a "Food Atlas" is made that would lay out the impacts of food and food production as they relate to the different capitals that are part of the eco-agri-food system in easily comprehensible terms. More broadly, as highlighted in Chapter 8, consumers can use the TEEBAgriFood Framework to better understand the constitution of sustainable diets, as well as the health implications of their current food consumption patterns, and the size of their current food footprints.

This all leads back to the discussion in Section 9.2.1 above regarding the credibility and legitimacy of information as a basis for change in practice. From a behavioural psychology perspective, at an individual or collective level, a person or group's world view and political perspective are often more important in determining openness to change than whether the information she receives is adequately convincing (Weber and Johnson 2009).
The intensive public relations campaigns led by major food and agricultural input companies have included support for policy dialogues, major media coverage of food issues and intensive lobbying of international aid organizations. The aim of this media and networking blitz has often been to position large-scale agroindustry's high-external input systems as the "only" way to reliably produce large volumes of food, and as champions of sustainability. These campaigns often mislead consumers, and are difficult to combat. A cacophony of narratives only serves to confuse the issues at stake.

Nevertheless, there is no question that the food industry has been going through a significant transformation over the past decade due in large measure to consumers' concern over their health and that of the environment from which food is sourced. The food localization movement has combined with concern for excessive reliance on long distance transport and trade for foodstuffs, whose freshness is questioned. Buying fresh food locally becomes a way for individuals to make a positive statement to their peers regarding their contribution to mitigating climate change, as well as to shore-up endangered family farmers and to protect prime agricultural lands near major urban centres.

To stimulate greater knowledge of externalities in the food system throughout society, alliances should be formed with non-farm communities whose interests in food quality and identity they share. Programs such as community-supported agriculture, direct marketing, recreational exchanges on farms and cities, cross-site visits, farms in community and state park systems, etc. have blossomed, and will serve an important purpose to build support for change in agricultural production practices and food quality along the value chain.

9.5 THEORY OF CHANGE AND ACTOR-RELEVANT STRATEGIES TO DESIGN INTERVENTIONS BASED ON TEEBAGRIFOOD

The previous sections of this chapter, by describing various contexts in which eco-agri-food policies are debated and negotiated, provide an overview of how different actors are involved in such processes. This final section proposes a synthetic view of the theory of change described throughout this chapter, and illustrates the consequences of this theory of change for the design and intervention strategies of future TEEBAgriFood studies

9.5.1 Prioritizing actors as points of entry for change

Analytically, actors mentioned above are of two types: the first are key players in a given food system whose actions are driving – or constraining – the system. These actors' behaviour and choices need to change if the food system is to evolve in sustainable ways. The second are actors desiring to bring a change in food systems by making use of TEEBAgriFood resources, thus collaborating with actors of type 1 to disseminate knowledge of the true costs inherent in the food system. Since it was shown above that information in itself may be insufficient to provoke a change, it will need to be mobilized by such actors (Majone 1989; Fisher and Forester 1993; Laurans *et al.* 2013; Mermet *et al.* 2014; Feger and Mermet 2017)

Another important analytical category introduced in the chapter is the notion of driver of change. For each actor group, there is a set of levers that determine the actor's behaviour and on which the agents of change can exert influence. Governments, or more specifically ministries, can make use of TEEBAgriFood results to frame negotiations with agribusiness regarding its agri-food policies. But there are also cases where a government (and even sometimes the very same government) will be a key actor that Civil Society Organisations (CSOs) will pressure, based on TEEBAgriFood results, to induce changes in legislation that will drive change in one or more nodes of the food system. Such aspects should be conceived in dynamic terms: actors and influencers can coexist in the same organisation and are competing to drive their organisation in a certain direction in a cascade of influence. For instance, a social movement may use a study to make a government undertake a change; the government will in turn use the study as well to make other actors change and so on. To illustrate this, actors are grouped in **Figure 9.5** below with a proposed relative position on the continuum axis between the influencer pole and the key actors pole.

These actors together participate to drive the agriculture-health-environment nexus, with different roles. For each type/subgroup of actors, levers and drivers of change are suggested, as well as indications on how TEEB outputs can be made relevant to these actors and levers in **Table 9.2**.

Figure 9.6 Agri-food actor group continuum (Source: authors).

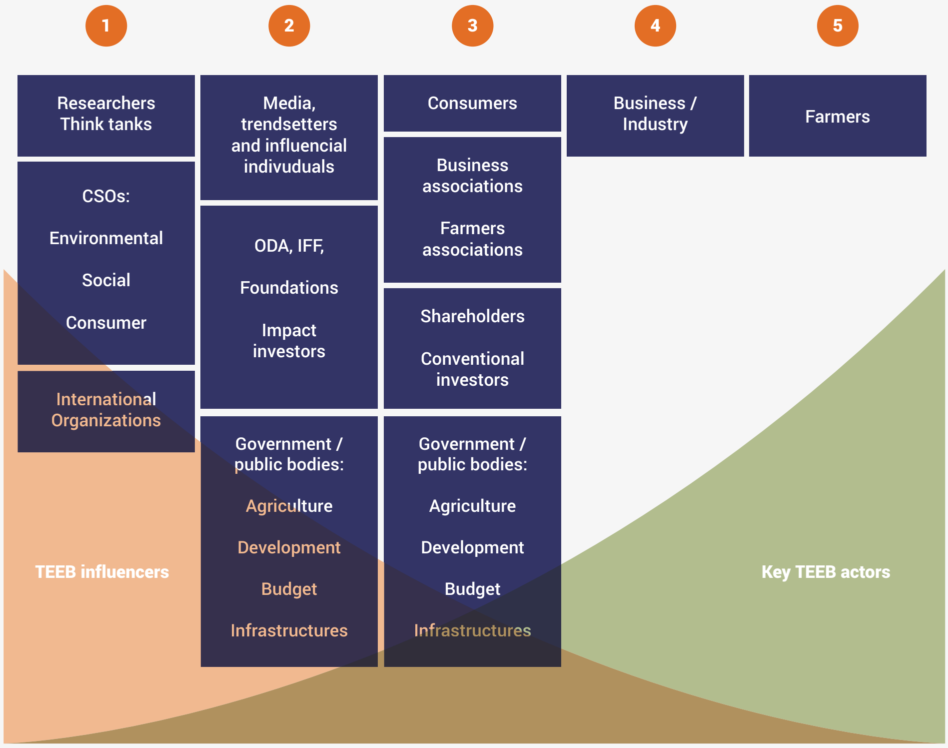


Table 9.2 Actors groups, typical levers and drivers of change and according relevant TEEB inputs (Source: authors)

Actor group (Figure 9.5)	Actor (Figure 9.5)	Lever / driver of change	Relevant TEEB input and how TEEB results could be translated
1	**Researchers and Think tanks**	Attention and support to research	Research avenues, blind spots to be addressed, policy-relevant pending questions
	CSOs	Availability of arguments Opinion awareness	Environmental, social and consumption consequences of unsustainable agriculture ((including environmental accounting such as Natural Capital accounts…)
	International Organizations	Governmental sensitivity Opinion awareness Policy perspectives Institutional	Social consequences of unsustainable agriculture
2	**Media, trendsetters and influential individuals**	Awareness of and sensitivity to impacts on well-being and immediate future Knowledge of opportunities and concrete solutions	Storytelling / success stories: Major, global as well as local concerns, and how they are addressed by innovative local and concrete solutions
	Overseas Development Agencies (ODA), International Funds, Foundations, Impact Investors	Profitability and sustainability indicators	Impacts of unsustainable agriculture on social and economic profitability Sustainable development Impact investments opportunities
	Governments: public bodies dealing with environment, health, consumption, social aspects and justice	Availability of: Norms, impact indicators (pollution / health thresholds) Feedback on policy implementation and best practices Policy perspectives (typical implementation pathways, w.r.t. taxes, subsidies, regulation) Opinion awareness and political support Reputation Accountability and cost-benefit ratios	Evidence on environmental, health and social impacts of unsustainable agriculture, for various geographical, social and economic contexts Illustrations / examples of best practices and of policy instruments and implementation Inclusion of governmental initiatives in inputs for media and trendsetters Indications on national and international commitments Policy evaluation indicators

3	**Consumers**	Change of social norms (esp. with respect to diet shift) Practical solutions for diet change Education and school kitchens Information on benefits from healthy and sustainable food Certificates and labels	Illustrations and Story-telling on relations between (un) sustainable agriculture and (un)healthy food, (un)healthy environment, … Practical examples / best practices of food system adaptation Practical recommendations Certification evaluation and mapping, indicators of informed consumer choice, information sources
	Business associations	Profitability and sustainability indicators Public support and guarantees with respect to long-term policy orientations Consumer awareness and political sensitivity Perspectives on future mainstream and alternative business models Clarity and stability of sustainability requirements	Evidence with respect to profitability (see also ODA…) Information on long term policy trends (past and future) Illustration of profitable sustainable business models Orientations for designing sustainability requirements in typical agro-food products
	Farmers associations	Indications on sustainable income, labour conditions, economic perspectives Others equivalent to Business associations	Illustration of impacts of sustainable agriculture on farmers social and economic condition (income, labour conditions and health) Training and education materials
	Shareholders and (conventional) investors	Profitability and sustainability indicators Long term economic perspectives Reputation of industry and businesses	See “business associations”
	Governments: public bodies dealing with agriculture, development policies, budget, infrastructure and utilities…	Collective profitability Cost-effectiveness ratios Reputation Long term perspectives, Demand and use	Cost-effectiveness of sustainable agriculture solutions Examples / illustrations of reputational risks Demand and use forecasts and scenarios

4	**Business / Industry**	See "business associations"	Case studies Illustrations Best-practice guidance, applying TEEB for business / Natural Capital Coalition's Natural Capital Protocol Business policy evaluation scorecards
5	**Farmers**	See "farmers associations"	Storytelling related to land tenure, investment profitability, market trends, income Illustration of improved profitability (reduced costs / improved access to market) from sustainable agriculture + identical to "media…" and to Business / industry

From this analysis stems an important conclusion for the ToC of TEEBAgriFood studies. To foster change in food systems, any study needs, during its design phase, to identify which potential influencers, in which typical contexts, it wishes to equip, in order to activate which lever on which actor group. Outreach strategies must be geared towards potential users, or even directly communicated towards certain actor levers.

9.5.2 Developing strategies to design and disseminate actor-relevant TEEBAgriFood studies

To respond to these challenges and to integrate the elements above, actors willing to make use of TEEB results to bring a change in the eco-agri-food system should adopt a three-tier approach to study design and strategy. The elements of this approach, listed below, concern different stages in the production process of a study based on the TEEBAgriFood Framework, but should also be seen as interacting with each other and partly overlapping in time.

- **Phase 1. Design a study and plan for intervention: context assessment and strategic framing.** As for any assessment and evaluation study that aims to deliver a message and eventually produce a change in society, TEEBAgriFood authors should understand the strategic context in which their study will intervene (Mermet 2011; Coreau 2017). What efforts have already been made to put key questions on the agenda and tackle them (e.g., environmentally harmful subsidies), by whom, with what effect? Did opposing actors enter into confrontation over these efforts, and if yes, how did they react to this newly provided information, and with what effects? How were coalitions on each side structured? Do they still exist today? These types of questions should enable author teams to identify the users and targets discussed above. Then, author teams should engage with different users to better integrate their own experience of the issues at stake (Turnhout *et al.* 2012) and co-construct parts of the study with them, to maximize the chances that the study has impact once released.

- **Phase 2. Conduct strategic outreach and intervention.** Once the study is produced, and even better while it is being produced, an intervention strategy should be designed. For the global scope results, for instance, the intervention strategy could be adapted to different national contexts and their own most salient issues at the agriculture-biodiversity nexus. Indeed, at a given point in time, national and regional arenas are agitated by different debates, and these debates frame how governments, media and the general opinion view different types of information on agriculture and biodiversity issues. If controversy is roaring in a given country on, for instance, pesticides, agricultural reform, or deforestation, the use of new results and messages will resonate stronger if some parts of the messages are highlighted to specifically contribute to these debates. This "strategic packaging" (Waite *et al.* 2015) of results consists of choosing which messages could be highlighted, in national press releases for instance, to better serve potential TEEB users in their quest for change. Beyond the media, specific discussions could be organized with potential users, and the TEEB team could guide them through the report to help identify the elements that could be of most efficient use in their own advocacy strategies, for instance to highlight aspects that had been previously put aside in debates. The discussions held in Phase 1 obviously constitute preparatory work for Phase 2.

- **Phase 3. Monitor and respond.** After results and messages are conveyed, monitoring activity will be useful: any given study only adds its voice in a concert of other flowing information, and to have impact it must be acted upon (Latour 2005). In the case of TEEB, this monitoring could focus on identifying: i) the positive impacts of the TEEB study, to foster reflexive learning for TEEB, and ii) how different biodiversity-agriculture debates evolve and how the study could be mobilized, even some years after publication. This could also include a monitoring of evidence for strategic ignorance of TEEB and TEEB-like results (see Section 2.1). This monitoring could then help build a response to this evolving context: issue a new press release targeted towards an emerging debate and to which previous TEEB results could contribute, or work with TEEB users to see how different actors could mobilize to try and combat detected ignorance mechanisms.

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(Footnotes)

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CHAPTER 10

TEEBAGRIFOOD AND THE SUSTAINABILITY LANDSCAPE: LINKING TO THE SDGS AND OTHER ENGAGEMENT STRATEGIES

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SUMMARY

Chapter 10 applies TEEBAgriFood's Theory of Change to develop specific engagement strategies for TEEBAgriFood. Transformations of the eco-agri-food system depend on alliances for change. Therefore, the chapter situates TEEBAgriFood in the normative framework provided by the Right to Food and relates it to other valuation initiatives. The chapter emphasizes TEEBAgriFood's contribution to the integrated implementation of the 2030 Agenda. By identifying and mapping the positive and negative externalities of specific eco-agri-food system measures, TEEBAgriFood identifies synergies and trade-offs between the SDGs. Proceeding like this, TEEBAgriFood supports follow up and review of the 2030 Agenda. Overall, the chapter emphasizes the benefits

CONTENTS

FIGURES, TABLES AND BOXES

CHAPTER 10

KEY MESSAGES

- **TEEBAgriFood is part of and adds value to several initiatives ranging from international science-policy interfaces to firm level accounting systems. It also supports the implementation of global agreements relevant to the eco-agri-food system.** The Right to Food, the Aichi Target, and the SDGs provide political reference points for actors seeking transformations in the eco-agri-food system.
- **This chapter aims to illustrate how the diverse actors identified in TEEBAgriFood's theory of change may adopt the findings of TEEBAgriFood to promote the transition towards greater sustainability**. To this end, the chapter places TEEBAgriFood in today's global sustainability governance context and suggests concrete engagement strategies for groups of actors.
- **Governments, businesses, and civil society should apply TEEBAgriFood as a tool for the implementation of the Sustainable Development Goals.** It corresponds to key principles of the 2030 Agenda, it supports the follow up and review processes envisaged by it, and it can become a much-needed tool in overcoming fragmented approaches to sustainability transformations in the eco-agri-food system.
- **Governments and businesses must become agents of the transition from financing agricultural production to food system finance.** Food system finance encompasses the range of financial incentives and disincentives to support transformations in the eco-agri-food system; the Addis Ababa Action Agenda provides the political reference point for this purpose.
- **There is also a need to create further ownership and accountability among businesses for transformations in the eco-agri-food system.** By including governments and civil society to enhance accountability, TEEBAgriFood Business Platforms represent an important step in this regard.
- **Empowered citizens are key to transforming the eco-agri-food system. To make informed decisions, citizens must be able to access relevant information.** Tailored TEEBAgriFood communication tools are pivotal in this regard and represent an important strategy to engage the general public.
- **The strategies developed in this chapter demonstrate how TEEBAgriFood could be used in achieving eco-agri-food system transformations:** (i) supporting a more encompassing understanding of the eco-agri-food system, (ii) reaching out to a broad range of constituencies to support alliance building to increase the leverage of those interested in changes in the eco-agri-food system, and (iii) offering a holistic analysis which supports identifying strategic interventions and setting priorities.
- Relevant as the proposed strategies may be, they do not aim to be comprehensive. Knowledge-based change depends on learning and iteration. Hence, **the proposed engagement strategies aim to offer a first starting point for joint efforts to further apply TEEBAgriFood's Evaluation Framework and its findings**.

TEEBAGRIFOOD AND THE SUSTAINABILITY LANDSCAPE: LINKING TO THE SDGS AND OTHER ENGAGEMENT STRATEGIES

10.1 INTRODUCTION

The term 'eco-agri-food systems' refers to the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food (TEEB 2015). TEEBAgriFood evaluates today's eco-agri-food system by using a holistic Evaluation Framework to inform on economically visible and invisible stocks and flows related to eco-agri-food systems that include social, cultural and behavioural issues and resilience concerns in analyses; it considers both monetary and non-monetary values1. As explained in detail in Chapter 6, the Evaluation Framework has been refined to reflect the evolutionary nature, through time and space, of the system as a whole but also the interactions between its component parts. Due to its holistic approach, TEEBAgriFood can learn from the various existing valuation approaches and contribute to them.

TEEBAgriFood supports sustainability transformations of the eco-agri-food system by: (i) contributing to a more encompassing understanding of the eco-agri-food system, (ii) strengthening alliance building to increase the leverage of those interested in changes in the eco-agri-food system by reaching out to a broad range of constituencies, and (iii) identifying strategic interventions and setting priorities.

TEEBAgriFood is highly relevant in today's global sustainability governance context. The Sustainable Development Goals (SDGs) and the Nationally Determined Contributions (NDCs), despite being significant elements of the global sustainability governance landscape, are also voluntary. The implementation of these voluntary agreements depends on encouraging diverse actors to participate, integrating different sources of knowledge and ensuring that cross-cutting issues are properly considered. TEEBAgriFood can help by providing information and knowledge through valuation. A precondition for this is tailored communication of TEEBAgriFood's findings. Further, the holistic analysis offered by TEEBAgriFood supports identifying the actors affected by and relevant to changes in the eco-agri-food system. Hence, TEEBAgriFood can contribute to the inclusion of a range of actors of the eco-agri-food system according to their rights, capacities, and needs. TEEBAgriFood can therefore contribute to the successful implementation of global agreements, including the Sustainable Development Goals (SDGs), the Paris Climate Agreement and the Aichi Biodiversity Targets.

To achieve a transformation of the eco-agri-food system, engagement strategies need to act in concert. For example, progressively steering investment decisions towards sustainability depends on a range of components of the eco-agri-food system. It depends on better enforcement of a human rights framework, not least for large-scale investments in land; it depends on a strengthened regulatory framework, in which sustainable investment decisions are taken; it depends on empowered citizens holding their governments accountable in implementing this regulatory framework; and, to just give another example, it depends on well-informed and empowered consumers able to make informed decisions about the products they consume. To contribute to change, TEEBAgriFood's engagement strategies need to live up to the complexity of the eco-agri-food system. This is not to say that transformations can only begin once enough resources are available to work on all of these engagement strategies simultaneously. Each of the engagement strategies addresses a specific aspect of the eco-agri-food system and can hence stand on its own.

This chapter showcases four such engagement strategies that illustrate how TEEBAgriFood's findings

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[1] The question of economic versus non-economic forms of valuation is touched upon but not fully developed in this chapter as this is this is a task for Chapter 6, which explains the elements of the TEEBAgriFood Framework.

can be used to support transformation processes in the eco-agri-food system. First, supporting the integrated implementation of the 2030 Agenda and the SDGs provides a unique opportunity to apply the findings of TEEBAgriFood. The 2030 Agenda is also linked to other global agendas such as health, biodiversity, climate and the right to food. Hence, TEEBAgriFood also contributes to informing other processes. Second, TEEBAgriFood's Evaluation Framework provides the basis to move from agricultural finance to funding sustainable food systems. In this context, the Addis Ababa Action Agenda (AAAA) becomes another relevant entry point for TEEBAgriFood. Third, businesses and industry are a further important target group of TEEBAgriFood. TEEBAgriFood showcases how sustainability can become profitable. Business platforms support knowledge exchange and create ownership of change strategies. Fourth, given its unique, comprehensive approach, TEEBAgriFood is well positioned to engage stakeholders and contribute to other initiatives. To this end, it is important to develop adapted communication strategies based on the application of the Evaluation Framework. Consumers are an important group to respond to the findings of TEEBAgriFood. This section therefore proposes an adapted communication tool to that end. The four intervention strategies described here are not exhaustive. They are examples of how the results of TEEBAgriFood can be used to support transformations in the eco-agri-food system.

This chapter illustrates how diverse actors in the eco-agri-food system may adopt the findings of TEEBAgriFood to promote the transition towards greater sustainability. The engagement strategies it proposes may serve as a source of inspiration for others how they can engage with or contribute to the TEEBAgriFood community.

10.2 TEEBAGRIFOOD: LEARNING FROM, AND CONTRIBUTING TO, EXISTING PROCESSES

As is now clear from Chapter 9 of this report, TEEBAgriFood's endeavour to strengthen the sustainability of eco-agri-food systems is not an isolated one. Many other initiatives have been working towards similar goals in the last years and even decades, each with its own approach and theory of change and its own target, depending on the actors involved and the context in which it has been implemented. Elaborating on Chapter 9, this section will present the processes through which a selected set of initiatives – ranging from international processes to national accounting systems and firm-level initiatives – are being implemented to identify where and how TEEBAgriFood could contribute to them. It will also place TEEBAgriFood in a broader normative context at the international level, showing how TEEBAgriFood can contribute in transformations of the eco-agri-food system.

10.2.1 A normative framework shaped by international processes

The need to increase the sustainability of eco-agri-food systems is longstanding. Many of the undesirable impacts on health, people livings and ecosystems (amongst other issues) have been highlighted over the past several decades (see Chapters 4 and 5). Most of those impacts have, in turn, been recognized by the international community, which has in response adopted a wide variety of multilateral agreements and international treaties (see section 4 of Chapter 9). Those treaties are now part of a very dense international institutional framework (for an analysis of the consequences of such density, see Orsini *et al.* 2013). The adoption of the 2030 Agenda and its Sustainable Development Goals, in September 2015, was seen as a key cornerstone to unify and give coherence to the many objectives set up by previous treaties in the field of sustainable development – though the SDGs are not binding commitments. This 2030 Agenda is thus considered as a strategic entry point for TEEBAgriFood. Other international agreements also deserve further attention, namely the Strategic Plan for Biodiversity 2011-2020 (and its associated Aïchi Targets) and the Right to Food (though the latter cannot be considered as an international agreement per se). Both are of utmost importance for TEEBAgriFood, though for different reasons. Aïchi Targets are, on the one hand, more specific than the 2030 Agenda regarding biodiversity, and given the normative anchor of TEEBAgriFood – namely biodiversity conservation – this level of detail is necessary. On the other hand, and as we will show below, the right to food is a cornerstone of international debates on food and goes beyond the sole focus on food security.

Implications of the Aïchi targets for eco-agri-food systems and TEEBAgriFood's contribution to their attainment

The Aïchi Targets were adopted in 2010 by Parties to the Convention of Biological Diversity, along with a more general Strategic Plan for Biodiversity 2011-2020. They consist of five broad strategic goals and 20 targets, out of which a good number relate, directly or indirectly, to the functioning of eco-agri-food systems. As part of a more general endeavour centred on biodiversity conservation (namely TEEB), TEEBAgriFood's potential contribution to the attainment of Aïchi Targets needs to be assessed carefully.

First and foremost, TEEBAgriFood should contribute to the achievement of Strategic Goal A for all aspects related to eco-agri-food systems. The goal reads as follows: “Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society.” It is comprised by 4 targets that are all relevant to TEEBAgriFood: make people aware of the values of biodiversity (related to eco-agri-food systems); integrate biodiversity values into poverty reduction strategies and national accounting; eliminate incentives – including subsidies – that are harmful to biodiversity; and implement plans for sustainable consumption and production. The TEEBAgriFood Evaluation Framework can contribute to the attainment of such targets, providing that two conditions are met: (i) that TEEBAgriFood results are widely disseminated (for targets 1 and 2); and that (ii) the assessments carried out at different scales uncover the underlying drivers of eco-agri-food systems functioning that have negative impacts on biodiversity.

TEEBAgriFood should also contribute to achieve other strategic goals, especially goal B (reduce direct pressures on biodiversity), by shedding light on the many links that exist between diet / consumption patterns, the functioning of food value chains and the destruction of certain ecosystems. This holds particularly true for targets 5 on halving deforestation by 2020, 6 on reaching a sustainable management of all fisheries and marine living resources and 7 on the sustainable management of areas under agriculture, aquaculture and forestry. Taking the case of deforestation, there is overwhelming evidence that the drive for new agricultural land was the main reason for deforestation of tropical forests between 1980 and 2000. Changes towards meat-based diets are a core reason for this (Gibbs *et al.* 2010; Meyfroidt *et al.* 2014). The same goes for the highly subsidized sector of deep sea fisheries, whose impacts on marine resources has long been documented (Morato *et al.* 2006; Benn *et al.* 2010; Sumaila *et al.* 2010), but for which legislative advances, for example at the level of the European Union, have been actively combated by industry lobbyists (Salomon *et al.* 2014). Here, the added value of TEEBAgriFood will not be to provide new information, as both topics (taken here as examples) have been widely covered by scientists. Neither will it be *only* to bridge the gap between policy makers and scientists, as several advocacy organisations have already raised awareness and knowledge of policy makers over the last decades. As indicated above, by offering a universal language for different valuation endeavours, TEEBAgriFood could contribute to broadening the alliance of actors working for change.

The role of TEEBAgriFood in the progressive realization of the Right to Food

Food security is a central concern. While the world food system produces enough food to feed the world, the number of undernourished or malnourished people has remained high. After a decade of decline, world hunger is on the rise again, to an estimated 815 million of undernourished people (FAO *et al.* 2017). To face the challenge of food insecurity, the international community has agreed upon a rights-based approach, through the adoption in 2004 of the Voluntary Guidelines to support the Progressive Realization of the Right to Food (FAO 2004). As pointed out by Mechlem (2004, p. 648), however, a rights-based approach should not be seen as a mean to achieve food security only, but rather as an end in itself that complements food security by dimensions of dignity, accountability and empowerment. However, the Right to Food has, to date, not yet systematically influenced state behaviour, nor have the structural reasons for food insecurity been overcome (Lambek 2015).

Contrary to general belief, the right to food does not only consist of the obligation made to states to ensure no one goes hungry and to provide food to those in need. The right to food entails two other state obligations, namely the obligation to respect and the obligation to protect. As phrased by Mechlem (2004, p. 639), the obligation to respect requires that “States refrain from interfering directly or indirectly with the enjoyment of the rights.” The obligation to protect requires States to “take measures to ensure that third parties such as individuals, groups, corporations or any entities do not interfere in any ways with the enjoyment of the right.”

The Right to Food could both benefit from the application of TEEBAgriFood and provide a human rights reference point for its application. An enhanced understanding of externalities could support States in uncovering the structural causes of food insecurity. This, in turn, helps States to protect the right to food of those communities by better addressing the structural causes behind the problem.

At this point, a specific point needs to be made regarding the “valuation language” TEEBAgriFood uses. If TEEBAgriFood is to assess the structural causes of food insecurity and the role of States in it, other forms of valuation beyond strict quantification and monetization will be needed. This is a matter of debate often raised by CSOs and academics. Critics of monetary valuation approaches suggest that valuation contributes to the economization of nature and hence supports alienating communities from the resources they rely on. Critics further remark that relying on economic valuation alone does not allow for fully accounting for the complexity of reality – especially on a topic such as the right to food (Vatn and Bromley 1994; Norgaard 2010). Therefore, particular attention needs to be paid to the unintended side effects of the valuation language adopted by TEEBAgriFood.

10.2.2 A field of action structured by numerous initiatives

As stated above, actors willing to make use of TEEBAgriFood operate in a field already structured by other initiatives. Maximizing complementarities between them is the purpose of this sub-section. It looks at four main types of initiatives launched and led by various institutions: international expert assessments, regional processes, national accounting systems, and firm level accounting systems. For each of them, a short presentation of their main intent, their structure and their functioning will be followed by an identification of the potential overlapping themes with TEEBAgriFood as well as an analysis of possible ways that TEEB can engage with them.

International processes and science-policy interfaces

Three main science-policy interfaces (SPI) are considered here: the Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) and the High-Level Panel of Expert (HLPE) of the Committee on World Food Security (CFS).

The IPCC was created in 1988 and is often presented as the "model" for most SPIs subsequently created – including the two other SPIs reviewed here. It assesses the current knowledge of climate issues and what is known about future trajectories, including the impacts of climate change and the options of adaptation, as well as the options for mitigation. Given the many relationships between agriculture, food security and climate change, the IPCC is clearly a key interlocutor for TEEBAgriFood. As of today, nearly 30 per cent of total anthropogenic emissions can be attributed to eco-agri-food systems (with some sources claiming as high as 50 per cent (Molla 2014), while many of the 570 millions of farms across the world are likely to be slightly to severely affected by climate change and thus will need to adapt – at least to increase their resilience to change (Vermeulen *et al.* 2012). Reports produced by IPCC working groups II on adaptation, and III on mitigation, are key sources of data for TEEBAgriFood. TEEBAgriFood can contribute by identifying economic and institutional levers that could help in reducing greenhouse gas emissions related to agricultural and food systems, as well means for adapting these systems to the impacts of climate change. The IPCC's Sixth Assessment Report (AR6) process, the "Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems" (forthcoming), could be an interesting opportunity to interface with TEEBAgriFood. The findings of TEEBAgriFood could also constitute an input to the future report of IPCC's Working Group II on climate change impacts and adaptation options, as well as to the future report by Working Group III on mitigation options. More generally, TEEBAgriFood could assess all eco-agri-food-related actions included in the Nationally Determined Contributions (NDCs) and foster a dialogue as to how to concretely implement these actions and the transformations they require in agricultural and food systems. Proceeding like this, TEEBAgriFood could provide important inputs to discussions on how to implement the Paris Agreement on climate (UNFCCC).

The IPBES was launched in 2011 after a bit more than five years of intense discussions. It aims to provide governments, civil society and the private sector with scientifically credible and independent up-to-date assessments of available knowledge regarding biodiversity and ecosystem services. In this respect, it relates to a large extent to food and agricultural issues, as eco-agri-food systems functioning has been one of the major drivers of biodiversity loss over the last several decades. This subject arose in the thematic assessment released by the IPBES (2016) on pollinators, pollination and food production, which aimed to "assess animal pollination as a regulating ecosystem service underpinning food production in the context of its contribution to nature's gifts to people and supporting a good quality of life." The report identified the transformation of agricultural systems as a major recommendation for improving the state of pollinator biodiversity worldwide. However, the assessment does not fully address the available means, such as phasing out harmful agricultural subsidies, which could help enact such a transformation of eco-agri-food systems (see Rankovic *et al.* 2016). Inputs from TEEBAgriFood could be helpful in future IPBES assessments that aim to work towards achievement of international commitments to stop biodiversity loss, especially in the framework of the Convention on Biological Diversity (CBD), such as Aïchi target 3 on eliminating subsidies harmful for ecosystems and the environment by 2020. By such contributions to IPBES, and/or by direct interactions with the CBD, TEEBAgriFood could be helpful in supporting the implementation of current commitments and in building CBD's next strategic plan (post-2020).

Finally, the HLPE was created in 2010 as part of the reform of the UN Committee on World Food Security (CFS). It aims to make visible the links between food security, agricultural development and the functioning of eco-agri-food systems. It has three main functions: (i) to assess the current state of food insecurity; (ii) to provide scientific advice on specific policy relevant issues; (iii) to identify emerging issues and help CFS members to prioritize future actions. Since its inception, it has published numerous reports that have been widely disseminated and commented by all actors advocating for more sustainable eco-agri-food systems, covering such various issue areas as land tenure and responsible agricultural investments, food security and price volatility, food security and social protection, sustainable agricultural development for food security and nutrition (including the role of livestock). TEEBAgriFood could positively engage with the HLPE and, more broadly, with the Committee on World Food Security, to contribute to future assessments of the expert body.

Each of these three science policy interfaces (SPIs) relies on multiple sources of data, including economic and non-economic, and communicate it through different channels. They perform three main functions. First, an informational function: assessments produced by SPIs can inform international negotiations and national and local debates (Riousset *et al.* 2017). SPIs show the state of knowledge concerning environmental changes, the risks that are entailed and what can be done, and by whom, to mitigate them. Reports produced by these institutions usually benefit from strong media coverage, which helps further raise awareness on environmental issues. Second, SPIs stimulate learning and capacity building: diverse actors are involved in the functioning of these institutions and they are places of intense exchanges on the multiple dimensions of environmental issues, creating an international community of people that is able to navigate within the technicalities of environmental science and policy. Finally, they also have an important legitimizing role for the actors and institutions focused on environmental concerns. By providing a well-structured, extensive and international state of the art analysis on a given environmental issue, they can help solve controversies and thus reinforce environmental policies against the strategic use of uncertainty by their opponents, especially at national levels (Chabason *et al.* 2016). For these reasons, linking TEEBAgriFood to the work of the SPIs is a strategic necessity.

A major point of controversy common to the three SPI under scrutiny relates to the use of economic valuation, which might explain why the assessments produced by such SPIs combine economic and non-economic approaches. While some participants contend that monetization would be a major step towards the adoption of adequate policies to enhance the sustainability of our eco-agri- food system, others indeed suggest it is better not to define economic values for every single issue (Seppelt *et al.* 2012). As a valuation approach, TEEB has also responded to these challenges (Sukhdev *et al.* 2014), but TEEBAgriFood needs to respond more specifically through further development of its methodologies. TEEBAgriFood can learn from SPIs on how to combine economic and non-economic valuations, and look to SPIs regarding mechanisms to ensure inclusive participation, the systematic release of updated reports, and their linkages to international intergovernmental processes.

National accounting approaches going beyond GDP

Two national accounting approaches are considered here: The System of Environmental-Economic Accounting (SEEA)[2] and the Inclusive Wealth Report (IWR). Both emerged following the need for development indicators that account for more than "just" economic growth. The idea of the SEEA was launched right after the first Rio convention to complement the existing United Nations System of National Accounts (SNA) created in 1953 (and revised twice since then). The latter was indeed unable to account for most of the natural capital. To overcome these limits, the SEEA was designed to take into account environmental assets in biophysical as well as monetary terms, considering seven main categories of resources: mineral and energy, land, soil, timber, aquatic resources, water, and other. As such, it does include all environmental assets that do not have direct economic value – with the explicit aim of valuing them in economic terms through the calculation of their net present value. Since its issuance in 2012, the SEEA central framework has been used in 15 developed and developing countries through the Wealth Accounting and Valuation of Ecosystem Services project (WAVES), carried out by the World Bank. The key objective of the project is to contribute to a wide implementation of the SEEA and hence to help develop an agreed methodology for measuring ecosystem services. The overall aim is to better link policy with natural capital accounts by providing decision makers with the "right" indicators.

The WAVES project, as well as the academic and practitioner community that has formed around the SEEA central framework, are important interlocutors for TEEBAgriFood. Methodologies and data can be shared between both initiatives; and it is hoped that methodological developments in TEEBAgriFood regarding the valuation of ecosystem services at each "stage" of the food chain could positively contribute to the advancement of the SEEA in national accounting systems. Last but not least, TEEBAgriFood can constructively engage with the of the SEEA-Agriculture, which intends to "enable the description and analysis of the relationship between the environment and the economic activities of agriculture, forestry and fisheries."

Importantly, TEEBAgriFood intends to go beyond the scope of the SEEA by including health issues in its valuation. As such, it could also benefit from the experience cumulated as part of the Inclusive Wealth Report (IWR) project, started in 2010. The framework used

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[2] It must be noted that the SEEA experimental ecosystem accounting (SEEA-EEA) is perhaps even more relevant for TEEBAgriFood than the SEEA-central framework (as well as the SEE for agriculture, forestry and fisheries). However, contrary to the SEEA central framework, these experimental frameworks have not been applied so extensibly so far and are not very well known. It will be important to continuously follow and monitor the further application of these frameworks.

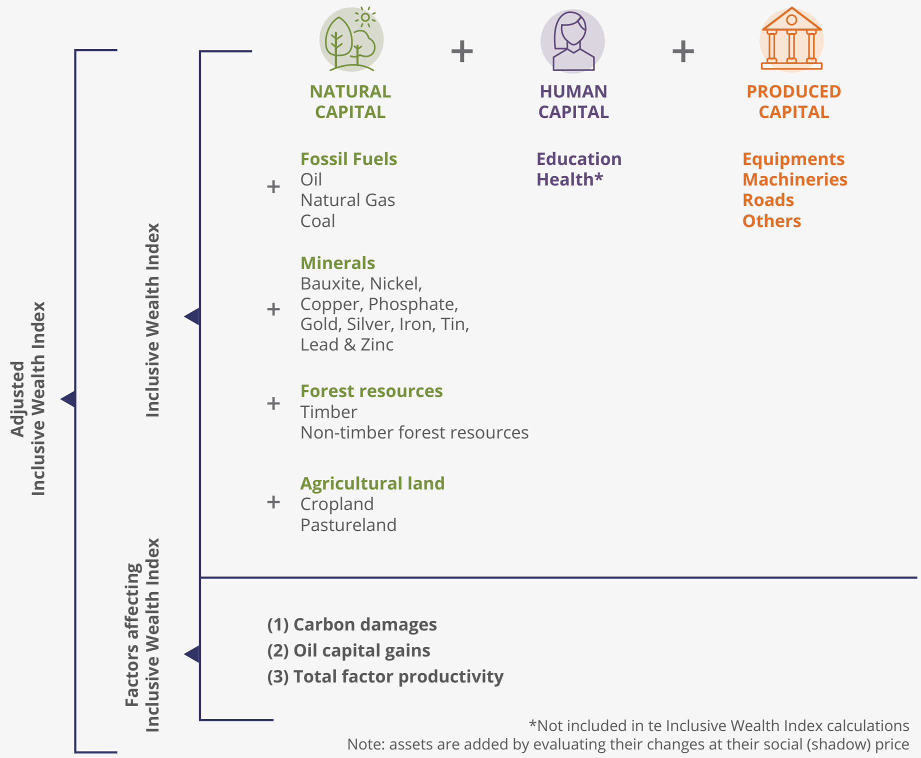
as part of the 2014 report is indeed quite comprehensive and includes, at national level, the valuation of three sorts of capital: natural, human and produced (see **Figure 10.1** and UNU-IHDP and UNEP 2014). This allows the authors of the report to assert that: "GDP is an inadequate measure for assessing long-term prosperity, and [that] education, health, and the environment [are] investments that will truly unleash the potential of young and interconnected populations around the world for development" (UNU-IHDP and UNEP 2014, p. 8).

TEEBAgriFood expands the range of capitals under consideration even further. Human capital considers the capacities of an individual, intrinsic to that person. Health and education are important examples in this regard. Yet, humans do not live in isolation – nor do they acquire their human capital independently of relations with fellow human beings. This web of social relations in which an individual is embedded is social capital (Portes 1998). Considering the four types of capital, TEEBAgriFood proposes a comprehensive Evaluation Framework for the analysis of the eco-agri-food system.

Firm level accounting / reporting approaches

Several accounting approaches aiming at uncovering the sustainability impact of firms have been developed over the last two decades. One can cite, inter alia, the Global Reporting Initiative (encompassing all sustainability dimensions), the Carbon Disclosure Project (focusing on firms' impact on carbon emission), the Natural Capital Project (working for example on global sourcing strategy for Unilever), and the Natural and Social Capital Protocols (hereafter NCP and SCP), put forth by the Natural Capital Coalition (NCC). The two latest protocols are reviewed here as examples. Their basic idea is to provide businesses with a tool that will "enable [them] to assess and better manage their direct and indirect interactions with natural [and social] capital" (FAO 2015). The NCC was launched in 2016 in order to develop the use of an accounting framework at the company level, supported by around 50 companies from diverse sectors, out of which 15 transnational companies for the agri-food sector. It gathers a broad range of stakeholders from different private companies, the World Business Council for Sustainable Development (WBCSD), the Food and Agriculture Organization of the United Nations (FAO), the International Union for the Conservation of Nature (IUCN), consultancies and major NGOs operating in the field of sustainable development (see Chapter 9 section 4.3). As tools that aim at helping companies to better manage their impacts on social and natural capital, the NCP and SCP start from the definition of the company's objective(s) and end with the choice of a (series) of actions and processes to be operationalized in the company in order to achieve the objective(s).

Figure 10.1 schematic representation of the Inclusive Wealth Index and the Adjusted Wealth Index (Source: UNU-IHDP and UNEP, 2014)



*Not included in te Inclusive Wealth Index calculations
Note: assets are added by evaluating their changes at their social (shadow) price

Regional processes

In between international processes and national and firm level accounting frameworks, regional processes deserve specific attention. Two of them are considered here: the African Ministerial Conference on the Environment (AMCEN) and the Asia-Pacific Economic Cooperation (APEC). The former was established in 1985 with the prime objective of halting and reversing the degradation of the African environment. So far, it has been in charge of several projects and missions related to biodiversity conservation, sustainable land management, the coordination of African countries for climate change negotiations or for the establishment of the 2030 Agenda. Similarly, the APEC gathers 21 countries from the Asia Pacific Region (including China, Russia, the United States of America and Indonesia) in a forum for economic cooperation. Since 2010, it has taken over the issue of food security as a major axis of cooperation, which has resulted in the issuance of the 2013 Food Security Road Map towards 2020.

What makes those regional processes interesting for TEEBAgriFood is the fact they can offer mid-range, well-structured political processes, in which TEEBAgriFood results could be used in order to accompany the formulation or the evaluation of specific public policies. In line with the third engagement strategy identified for TEEBAgriFood (see section 10.3), the APEC process could also offer good entry points to establish contacts with businesses of the region through the intermediary of the APEC business advisory council.

This review of other initiatives is cursory at best. Yet it demonstrates that TEEBAgriFood is embedded in a field already structured by other initiatives. It can learn from them and contribute to them. Given their number and their variety, ranging from international science-policy interfaces to firm level accounting systems, a key issue for TEEBAgriFood practitioners will be to define clear and strategic ways on how to engage with stakeholders revolving around eco-agri-food systems' governance. Section 10.3 will deal with this question in more details and offer options in this regard.

10.3 FOUR SPECIFIC ENGAGEMENT STRATEGIES FOR TEEBAGRIFOOD: APPLYING THE THEORY OF CHANGE OF TEEBAGRIFOOD

Chapter 9 of this report highlights the need to develop targeted outreach strategies geared towards particular actors that can use the outcomes of TEEBAgriFood to make decisions that transform eco-agri-food systems. Against this backdrop, this chapter proposes four engagement strategies that emphasize how TEEBAgriFood can be used to address different target groups, and outlines next steps in the application of TEEBAgriFood including: (i) supporting a more encompassing understanding of the eco-agri-food system, (ii) increasing the leverage of those interested in changes in the eco-agri-food system through alliance building, and (iii) offering a holistic analysis which supports identifying strategic interventions and setting priorities.

10.3.1 Supporting the integrated implementation of the 2030 Agenda

On 25 September 2015, the 193 Member States of the United Nations adopted the 2030 Agenda for Sustainable Development along with 17 Sustainable Development Goals (SDGs) and 169 targets (UN 2016). Devised by countries after arguably the most intensive multi-stakeholder consultation in UN history, the 2030 Agenda with its SDGs and targets are perhaps the most comprehensive framework to date that aims to shift development patterns towards more sustainable pathways. Staying true to the essence of the sustainable development concept popularized at the first United Nations Conference on Environment and Development in Rio de Janeiro (1992), the SDGs and the 2030 Agenda call for the integration of the social, economic, and environmental dimensions of development. The 2030 Agenda represents a holistic and systemic vision to adequately address challenges to sustainable development. Member states adopted the principle of "leaving no one behind" as one of the guiding principles for SDG implementation. The principle of "leaving no one behind" responds to the growing evidence that all over the world, in countries rich and poor, groups of people are consistently being left out of development progress because of deeply entrenched and intersecting inequalities (Kabeer 2010). Last but not least, the SDGs are universal in nature, which makes them applicable to rich and poor countries alike. This holds the potential for blurring traditional North-South dynamics that have framed development practice for decades and for promoting South-South and South-North cooperation and mutual learning in various areas covered by the SDGs.

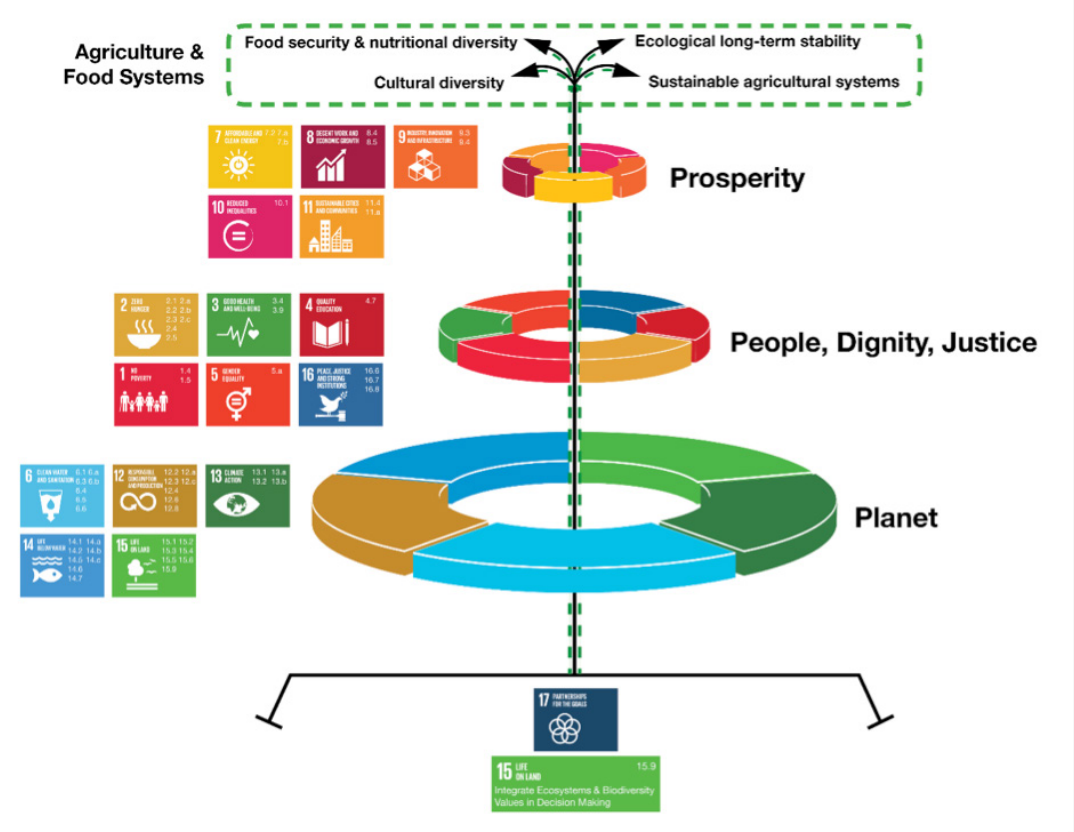
Analyses of the level of interdependency between the different SDGs have outlined interlinkages between all the goals (Waage *et al.* 2015; Le Blanc 2015). This certainly applies to SDG2 on zero hunger, which is linked with all other SDGs at goal level (Nilsson *et al.* 2016; Nilsson *et al.* 2017). If all the direct and indirect interlinkages between natural, human, social, and produced capital were to be considered, the eco-agri-food system is probably of relevance to all the SDGs and their targets.

Figure 10.2 illustrates that interlinkages can be identified between eco-agri-food systems and all the SDGs. We do not aim to create an exhaustive list of the SDGs, targets and indicators that relate to eco-agri-food systems, just several examples.

With more than 800 million people suffering from hunger worldwide, ensuring that the world provides enough food that is safe, affordable and nutritious (SDG2) is one of the biggest challenges facing the 2030 Agenda (TEEB 2015). Agriculture and food production has a major impact on the environment as the main driver of land use change, the biggest consumer of freshwater and a major contributor of greenhouse gas emissions. TEEBAgriFood is further highly relevant for targets under SDG1 on ending poverty, SDG3 on health, SDG5 on Gender, SDG6 on water, SDG7 on energy, SDG13 on climate change and 15 on life on land (Nilsson *et al.* 2017). In addition, eco-agri-food systems are closely linked with SDG10 on reducing inequalities, as demonstrated by the fact that the majority of the global poor continue to be smallholder farmers.

Theis illustration emphasizes that these interlinkages can appear in the form of synergies and trade-offs between the goals. In terms of TEEBAgriFood, these interlinkages represent the very externalities that are at the centre of TEEBAgriFood's approach. Given the complexity of the agenda and in order to support its integrated implementation, there is a need for tools that help identify measures that create synergies (positive externalities) and reduce trade-offs (negative externalities). TEEBAgriFood can contribute to the implementation of the SDGs as an indivisible set by mapping the linkages (externalities) between the different goals.

Figure 10.2 SDGs three-tiered structure and links to eco-agri-food systems. Source: authors, adapted from EAT (2016).



The TEEBAgriFood Framework is guided by three principles: universality, whereby the Framework is applicable to any geographical, ecological or social context; comprehensiveness, which means that any significant impacts of the food system, or any material dependencies, are considered no matter whether they be economically visible or invisible; and inclusion also of qualitative, physical, or non-monetary terms that support multiple approaches to assessment. These principles fall in line with the principles guiding the implementation of the SDGs. In short, the interdependent nature of the 2030 Agenda and the characteristics of TEEBAgriFood make TEEBAgriFood a natural candidate to support the integrated implementation of the SDGs.

One important avenue for TEEBAgriFood to support the integrated implementation of the 2030 Agenda is by supporting follow up and review processes at the national and global level. At the Rio+20 Conference, Member States agreed to set up an intergovernmental High-level Political Forum (HLPF) to coordinate and oversee implementation of the 2030 Agenda. Today, the High Level Political Forum is tasked with providing political leadership, guidance and recommendations for the implementation, follow-up and review processes of sustainable development commitments. It is responsible for strengthening the integration of the three dimensions of sustainable development in a holistic and cross-sectoral manner.

The issue of how to track progress against the SDG goals at the national and global level has generated a lively debate between governments, non-state actors and the UN. The definition of a 230-global indicator framework to monitor progress on the 17 SDGs and its 169 targets has raised questions on whether a monitoring framework that is divided among goals and targets can adequately report on an indivisible agenda. There are also concerns regarding the level of integration achieved in the "Voluntary National Reviews" by UN Member States and within the global progress assessments, the so-called "Thematic Reviews." The experience with thematic reviews so far suggests that this tool requires further strengthening. In 2017, the HLPF reviewed SDG 2 on food security alongside other relevant SDGs for the eradication of hunger, such as poverty and gender. The review was not, however, conducted in an integrated way. Any discussion on linkages at the global level was missing (Müller and Lobos Alva 2017). The same holds true for the "Voluntary National Reviews" (VNRs). An analysis of the VNRs submitted in 2017 revealed a lack of integration in the reporting, if not in the implementation of the 2030 Agenda within countries. TEEBAgriFood can assume an important role in strengthening these national and global-level reporting instruments. If TEEBAgriFood empowers voices often neglected in decision-making as planned, its relevance for the successful implementation of the 2030 Agenda will only increase.

In sum, the 2030 Agenda offers a strategic window of opportunity since it is accompanied by high-level political commitment. Further, TEEBAgriFood is a natural candidate to address the challenges integrated implementation of the 2030 Agenda by identifying and mapping the positive and negative externalities of specific measures with regard to achieving different SDGs. In this context, the follow up and review mechanisms of the 2030 Agenda offer a concrete entry point for TEEBAgriFood and are in the need of strengthening by the type of insights offered by TEEBAgriFood.

10.3.2 TEEBAgriFood and the Addis Ababa Action Agenda: Charting the Way Towards Food System Finance

The previous section underlines the importance of the 2030 Agenda as it provides the political backing for the integrated transformation of the eco-agri-food system. TEEBAgriFood also has immediate relevance to another part of the 2030 Agenda: the discussion on financing sustainable development.

Paragraph 39 of the 2030 Agenda emphasizes the role of a renewed Global Partnership to generate the necessary resources ("means of implementation") to finance sustainability transformation. UN Member States agreed on the structure and principles of this Global Partnership at the Third International Conference on Financing for Development in Addis Ababa in July 2015. The outcome document of this conference, the Addis Ababa Action Agenda (UN 2015), was subsequently endorsed by the UN General Assembly and forms an integral part of the 2030 Agenda.

TEEBAgriFood can contribute to the Addis Ababa Action Agenda (AAAA) in no small part because it offers a holistic evaluation of the food system (Sukhdev *et al.* 2016). This applies to the interlinkages between the components of the eco-agri-food system, as well as to the evaluation of strategies by which to intervene in the system. That is, changes must go beyond agricultural production. In terms of financing, this implies moving beyond a focus on financing agricultural production to a broader focus on food system finance. Food system finance encompasses all financial incentives and disincentives that could be used to steer the eco-agri-food systems towards sustainability. Food system finance hence blends the discussion on financing agricultural production with the discussion on appropriate economic instruments for assessing environmental and health policy.

There is an urgent need to increase investments to eradicate hunger and malnutrition globally and to redirect investments within the eco-agri-food system towards sustainable practices. Chapters 3 to 5 of this report describe the magnitude of the challenge at hand.

Estimates arrive at a financing volume of up to 400 billion USD per year in land and agriculture alone (UN 2014). Against the backdrop of these financing requirements, the AAAA (UN 2015) highlights the importance of broadening the financial base of sustainability transformations. This implies, for example, going beyond the public sector, as well as, regarding developing countries, to move beyond Official Development Assistance (ODA). At the most general level, the AAAA emphasizes the need of all actors to act in concert to finance the urgently needed sustainability transformation of the eco-agri-food system.

For Food System Finance to function it must move beyond publicly funded agricultural production financing. Goedde *et al.* (2015) estimate the value of food and agribusiness to be USD 5 trillion. Therefore, changing investment decisions by private actors in food and agribusiness represents a significant funding source for a sustainable food system (section 10.3.3 elaborates on this point). Pollution taxes are one way to internalize externalities by taxing the polluters ("make the right people pay") (TEEB 2011). Take the example of non-point source water pollution: in high-income countries and emerging economies agriculture is a larger polluter of inland and coastal waters than human settlements (FAO and IWMI 2017). In the world's groundwater aquifers, nitrate is the most common chemical contaminant (ibid.). In the UK alone, the overall costs of agricultural water pollution are estimated at 500 million pounds Sterling for 2003/04 (Parris 2011). Ambient taxes - taxes to be paid by all potential polluters in a given region - and input taxes (fertilizer taxes) are economic instruments to address this problem (Xepapadeas 2011). An evaluation of all the externalities of the food system is a pre-condition to the design and implementation of these instruments.

As a holistic Evaluative Framework, TEEBAgriFood: (i) supports a more encompassing understanding of the eco-agri-food system, (ii) supports alliance building to increase the leverage of those interested in changes in the eco-agri-food system, and (iii) supports the identification of strategic interventions and setting priorities through holistic analysis.

This section provides examples of each of these uses of the Framework regarding Food System Finance. (A comprehensive treatment of Food System Finance is beyond the scope of this section.)

- **Using the TEEBAgriFood Framework to identify strategic interventions and to set priorities: Taxing environmentally harmful and unhealthy practices to generate resources for sustainability transformations.** Chapter 4 describes the obesity crisis generated by the current eco-agri-food system. As the world is becoming increasingly urban, obesity increasingly affects the poorer populations and the lower-middle classes in large cities due to the increasing consumption of ultra-processed food with high sugar, fat, and salt content. At the same time, resources spent on ultra-processed food do not support local food production. Beyond negative health impacts, these processed foods undermine the development of a sustainable urban food system. The High-level Expert Committee to the Leading Group on Innovative Financing for Agriculture, Food Security and Nutrition (2012) proposes taxing fat and sugar products as an innovative funding source for the implementation of food security and nutrition policies. In this context, the TEEBAgriFood framework can be used to identify food security and nutrition interventions that create systemic benefits and tax harmful activities. To spin the example of the urban eco-agri-food system further: there is now increasing evidence that urban agriculture does not only enhance food security and improve the nutritional status of urban poor (Masvaure 2016; Ayerakwa 2017; Omondi *et al.* 2017), urban agriculture also contributes to women's empowerment (Olivier *et al.* 2017), and has environmental benefits (Aubry *et al.* 2012). Urban agriculture is not only important in developing countries, but also in poor neighbourhoods in high-income countries (Parece *et al.* 2017). Yet those practicing urban agriculture need to cope with lack of access to finance (Cabannes 2012). Linking a tax on products with high sugar, fat, and salt content with support to urban gardening represents one example of a systemic intervention in the eco-agri-food system. This example showcases the type of analysis – at a very coarse scale – that is supported or enabled by applying the TEEBAgriFood Framework to help with decisions on investment priorities and possible funding sources.

- **Using the TEEBAgriFood Framework to obtain a more encompassing understanding of the eco-agri-food system: Approaching future externalities and their financial implications.** Since 2011, environmental risks have featured prominently in the World Economic Forum's Global Risk Report, both in terms of likelihood of entry and in terms of impact. Externalities of the eco-agri-food system will influence payments to be made by the insurance sector, within agriculture (e.g. crop failure) and beyond it (e.g. damage to infrastructure because of a landscape's reduced water holding capacity). An enhanced understanding of externalities allows for a more encompassing conversation on the role of the insurance sector within the eco-agri-food system. The insurance sector matters both as an investor (e.g. UNEP (2017) estimates the managed assets to be worth USD 31 trillion) and as an actor setting incentives for its clients to pursue sustainable practices. Take the example of land degradation: healthy soils make for a more resilient agricultural landscape that can store water and make plants less prone to the effects of drought. The Economics of Land Degradation Initiative shows that investments in land across different production systems are less costly than bearing the costs of inaction (Nkonya *et al.* 2016). Yet sustainable land management often requires upfront investments, which only yield returns later on (see, for example, Meinzen-Dick and Di Gregorio 2004). In instances such as these, investments by the insurance industry and financial incentives in the form of reduced insurance fees might support necessary changes in agricultural practices.

- **Using the TEEBAgriFood Framework to supports alliance building across different constituencies: Redirecting agricultural subsidies.** According to OECD (2017), financial support to individual farmers in 2014 - 2016 was on average USD 519 billion per year (for the 52 countries covered by the report). Taking the example of agriculture in the European Union, these subsidies contribute to environmentally harmful practices. Redirecting these subsidies could have major impact on sustainability transformations. Regarding the reform of the European Union's Common Agricultural Policy, proposals call for tying direct payments to farmers more strongly to sustainability criteria. In essence, these proposals claim that subsidies should made be available only for agricultural production that generates positive externalities ("Public money for public services") (Lischka 2016). Payments for ecosystem (PES) services offer a source of revenue for sustainable agricultural practices (Engel *et al.* 2008). Yet markets for ecosystem services are only slowly emerging and require a strengthened enabling framework. Redirecting agricultural subsidies could support creating this enabling framework for PES schemes. Changing the allocation of subsidies requires broad political alliances to create the necessary leverage. As TEEBAgriFood reaches out to the environmental and health communities it goes beyond the "usual suspects" in environment and agriculture and thereby broadens alliances for change.

There is tremendous financing needed to feed the future's 9 billion people in a sustainable way. The global framework for financing the 2030 Agenda, the Addis Ababa Action Agenda (UN 2015), requires tools such as TEEBAgriFood to support countries in designing their financing strategies for the eco-agri-food system, tailored to the complexities of the eco-agri-food system.

10.3.3 Establishing TEEBAgriFood Business Platforms

Chapter 9 of this report on TEEBAgriFood's theory of change identifies business and industry as one major actor group for which strategies of engagement need to be specially tailored. This section explores business platforms as one promising area for TEEBAgriFood to engage with leaders and key actors in the business sector. First we review the current state of the debate on multi-stakeholder platforms processes in order to elucidate their role in global environmental governance and the lessons learned from setting them up in different contexts. Potential rationales for establishing such platforms specifically for the business sector will also be explored. Finally, and in order to draw conclusions, this section will present some of the most current and relevant examples of business-specific initiatives and their unifying characteristics to show which promising features should be considered by TEEBAgriFood Business Platforms.

TEEBAgriFood business platforms enter a very crowded landscape of initiatives, which increases the need to clearly define their added value. TEEBAgriFood business platforms' added value could be: a) informing businesses to recognize, and where appropriate, capture hidden flows of the eco-agri-food systems complex in their decision-making, b) going beyond the focus on natural capital alone (as in other initiatives) and include all relevant physical, economic and non-economic (capital) stocks and (physical) flows, allowing for entry points and applications for measuring value addition, and/or c) systematically addressing both ecosystem health and human health impacts and dependencies of eco-agri-food systems. This section also warns of the need to ensure TEEBAgriFood Business Platforms take measures to avoid pitfalls: such as assuming all stakeholders enter the dialogues with an equal decision-making power or have the same stake in the discussions, assuming multi-stakeholder platforms are "naturally" inclusive and democratic, or failing to acknowledge and properly ensure sufficient resources for participation.

A precondition to arriving at any conclusion regarding the potential of TEEBAgriFood Business Platforms is an understanding of the current state of the wider debate on multi-stakeholder platforms or partnerships. Multi-stakeholder processes emerged in the landscape of approaches to international policy making at the UN Earth Summit, held in Rio in 1992 (Murphy and Coleman 2000). Hemmati (2002, p.2) provides the following definition:

"The term multi-stakeholder processes describes processes which aim to bring together all major stakeholders in a new form of communication, decision-finding (and possibly decision-making) on a particular issue. They are also based on recognition of the importance of achieving equity and accountability in communication between stakeholders, involving equitable representation of three or more stakeholder groups and their views. They are based on democratic principles of transparency and participation, and aim to develop partnerships and strengthened networks

among stakeholders. MSPs cover a wide spectrum of structures and levels of engagement. They can comprise dialogues on policy or grow to include consensus-building, decision-making and implementation of practical solutions. The exact nature of any such process will depend on the issues, its objectives, participants, scope and timelines, among other factors."

Multi-stakeholder platforms or partnerships are becoming a thriving and recognizable instrument of global environmental governance. They are usually expected to offer suitable conditions for collective decision-making, the space to acknowledge the increasing role of non-state actors, and the necessary flexibility to break through deadlocked multilateral negotiations. Empirical experience shows that multi-stakeholder platforms are proliferating as a tool to exchange knowledge, contribute to creating ownership for change strategies and to increase accountability (also of the business sector). Their role, relevance and capacity to meet these expectations is now a widely studied phenomenon (Parkins and Mitchell 2005; Martens 2007; Andonova 2010; Bexell *et al.* 2010; Fuchs *et al.* 2011; Pattberg *et al.* 2012; Biermann *et al.* 2012; Weiss and Wilkinson 2014; Beisheim and Liese 2014; Chan *et al.* 2015). The main concerns regarding their effectiveness focus, for instance, on their potential to increase the already overwhelming decision-making power of private actors in international political priorities (Martens 2007), the politics of membership and decision-making, as well as the weakening of government responsibility (Nasiritousi *et al.* 2015). TEEBAgriFood business platforms need to carefully consider specific countering strategies, for instance by ensuring they are not "business-only" and exclusive, by ensuring sufficient resources for wider participation, and by adopting democratic decision-making structures.

Multi-stakeholder platforms can ideally: i) create a space for exchange of different perspectives and knowledge in a more flexible setting, ii) ensure accountability for the actions of the actors involved and ultimately, iii) support decision making and the development of strategies that can later support and influence more official and binding discussions, when needed. At the same time, one needs to remain realistic about the potential of multi-stakeholder platforms. Imbalances in power relations, lack of accountability and strong reporting mechanisms, as well as the lack of a strong commitment to support the active participation of social and peasant movements and small businesses could all threaten the actual contribution of such platforms.

But what would be the purpose or rationale for establishing such platforms, specifically for business and focusing on eco-agri-food systems? First of all, the TEEBAgriFood Framework sheds light on the range of actors involved in the eco-agri-food system. The need for collaborations and multi-stakeholder approaches in the food and agriculture sectors emerges from the magnitude of the needed transformation in order to make our food systems sustainable. Therefore, many efforts would need to converge, and the existence of such platforms would aim at harnessing the transformative power of these actors to ensure coherent actions. But there are several other related arguments that are rooted in the business case for sustainability, on normative questions and on the potential key leadership of business actors. A common unifying paradigm, which has gained traction over the past two decades (Haanaes *et al.* 2013), and can drive TEEBAgriFood business platforms forward, involves the motivation to make sustainability profitable. BSDC (2017) states that a global food and agriculture system in line with the SDGs would deliver nutritious, affordable food for a growing world population, generate higher incomes – especially for the world's 1.5 billion smallholders – and help restore forests, freshwater resources and vital ecosystems. It further sets the economic value of this transformation to sustainability at "more than US$2 trillion by 2030" (ibid., p.8). Given TEEBAgriFood's valuation approach, business actors are a natural target group. Companies make decisions based on various risks and opportunities (operational, regulatory, reputational, market and product, and financing), and accounting for value additions in supply chains can allow for companies to identify these, and take appropriate action (TEEB 2012). Next to the business case for sustainability, business platforms could be shaped and informed by the normative responsibility of this sector to change towards more sustainable and socially responsible practices. From this perspective, the focus is on the growing recognition of the need to address intrinsic inequalities in the way food is produced and distributed. As the producers, manufacturers and retailers of most of the world's food (and non-food agricultural products), business has a responsibility to help achieve transformation. The potential leadership of business actors for sustainable development has been highlighted in the framework of the 2030 Agenda, where business leaders committed to support the achievement of the SDGs. This was further demonstrated by the appointment of the CEO of Unilever as one of seventeen advocates for the SDGs.

Before the purpose, aim and focus of TEEBAgriFood business platforms can be determined, it is imperative to put their role and added value in perspective, especially compared to other platforms that aim to bring business actors together. Visser *et al.* (2015) provide a good overview in their CSR International Research Compendium, with a focus on environment. Aubert (2017) identifies the emergence of at least a dozen multi-stakeholder initiatives in the field of food and nutrition security and agricultural development between 2008 and 2016, and remarks that all of them involve companies from different segments of food chains, most of them being large and often transnational corporations. Section 10.2 of this chapter outlines that TEEBAgriFood can - and should -

learn from related initiatives and complement them; there are several examples of business-focused or business-led initiatives that would be relevant in the establishment of TEEBAgriFood business platforms. These initiatives seem to present certain unifying characteristics to different degrees: they aim to produce new information or tools, they focus on increasing collaboration and on the joint development of strategies, they are created by the self-initiative of business actors and at times, they go beyond the business sector to include different actors. In terms of platforms focused on producing new information to inform decision-making, the global multi-stakeholder collaboration "Natural Capital Coalition" (NCC) - formerly the TEEB for Business Coalition - was formed in 2014 in order to harmonize approaches to natural capital, promote a shift in behaviour that enhances natural capital and support the evolution of an enabling environment that both aids natural capital thinking and integrates it into other initiatives (NCC 2015). The protocol does not, however, explicitly list or recommend tools or methodologies and focuses instead on informing internal decision-making.

Evolving examples of platforms with a focus on the joint development of targets, strategies and their implementation include the Global AgriBusiness Alliance (GAA) and the Food and Land Use Coalition (FOLU). GAA is an international, private sector alliance launched in 2016 and led by the CEOs of forty-one major companies from the agri-business sector. GAA has the aim to "tackle environmental, social and sustainability challenges to improve the resilience of farmers across the world" (GAA 2016). The alliance also focuses on supporting the achievement of SDG 2: "end hunger, achieve food security and improved nutrition and promote sustainable agriculture". Within the GAA, private sector companies across the entire value chain of food and non-food crops are gathered to focus on sustainability and development challenges in the sector. As the companies operating closest to 'farmgate', GAA members aim to make advances in tackling the seemingly intractable challenges facing supply chains. A more recent example is the establishment of the FOLU by the Business and Sustainable Development Commission and the New Climate Economy leadership. FOLU is a self-governing coalition that has evolved from a few organisations reaching out to each other to try and address the complexity of the food and land use systems. FOLU has a set of three strategically linked work programmes: (1) developing global and national targets and pathways towards sustainable land-use and food systems, (2) identifying and supporting business solutions, and (3) implementing national and local solutions. Results of the work will be compiled into a global synthesis report to be launched during the World Economic Forum in Davos in 2019 (EAT 2017; Schmidt-Traub 2017).

Both GAA and FOLU are examples of platforms that were created by business leaders as an initiative coming from within the sector. There are also platforms that go beyond the business sector to include science and civil society. The NCC, for instance, purposely goes beyond the business sector and engages organizations, for instance, from government, science and civil society. FOLU also goes beyond the business sector. With over 30 members, it includes businesses, policy makers, foundations, investors, academics, international organisations and members of civil society.

There are several aspects that TEEBAgriFood business platforms could learn from and contribute to as regards the initiatives presented above, namely, the aim to jointly develop new information and strategies, the targeted support of global sustainable development agendas, the need to ensure accountability and reporting mechanisms and the inclusion of stakeholders beyond the business sector, as well as from small businesses. Similar to the NCC, TEEBAgriFood business platforms could help inform businesses, and where appropriate, capture hidden flows of the eco-agri-food systems complex in their decision-making. TEEBAgriFood efforts would, however, go beyond the focus on natural capital alone and rather include all relevant physical, economic and non-economic (capital) stocks and (physical) flows, allowing for entry points and applications for measuring value addition. TEEBAgriFood Business Platforms could also, for instance, address the lack of proposed tools or methodologies by the NCC with the TEEBAgriFood Evaluation Framework (presented earlier in this report) and disseminate it so that it can be used by a wide range of stakeholders and applied towards changes in the eco-agri-food system. In line with the engagement strategy put forward in section 10.3.1 of this chapter on "supporting the integrated implementation of the 2030 Agenda", an explicit focus by TEEBAgriFood business platforms on their potential contribution to global sustainable development agendas, such as the 2030 Agenda, would be desirable. This type of analysis needs to go beyond one single SDG to recognize the potential effects and interlinkages to other themes covered by the SDGs and their links to different parts of eco-agri-food Systems.3 An analysis for TEEBAgriFood and its link to the SDGs is provided in section 10.3.1 of this chapter. In addition, according to the definition of multi-stakeholder processes and the empirical experiences with this type of platform presented earlier in this section, it would be highly advisable for TEEBAgriFood business platforms to go beyond the business sector and engage organizations, for instance, from government, science and civil society. This would be a promising approach in order to mitigate the risk of becoming overly exclusive and to allow for different perspectives to be taken into account. Equally, TEEBAgriFood business platforms should acknowledge

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3 For more on the SDGs as a network and a system please see: Waage *et al.* 2015; Le Blanc 2015; Nilsson *et al.* 2016; Nilsson *et al.* 2017.

the power imbalances that arise when multinational corporations, States, civil society groups and smaller companies enter a multi-stakeholder process (Aubert 2017). This issue can only begin to be addressed through the inclusion of participatory formats and strong reporting mechanisms to increase accountability, especially of large companies and States.

TEEBAgriFood Business Platforms need to provide business-specific strategies and entry points for the sustainable transformation of eco-agri-food systems. Nonetheless, they ought to acknowledge that these strategies and entry points cannot be identified and developed by business alone, as other key actors provide knowledge that could avoid future conflicts and the lack of consideration of important potential negative impacts of certain strategies. In particular, a participatory multi-stakeholder approaches to TEEBAgriFood business platforms should aim to increase the accountability of business actors as their increasing power and influence in decision making has been intensely criticised in the framework of multi-stakeholder processes (Parkins and Mitchell 2005; Martens 2007; Andonova 2010; Bexell *et al.* 2010; Fuchs *et al.* 2011; Pattberg *et al.* 2012; Biermann *et al.* 2012; Weiss and Wilkinson 2014; Beisheim and Liese 2014; Nasiritousi *et al.* 2015; Chan *et al.* 2015). Finally, there are several aspects of eco-agri-food systems on which TEEBAgriFood Business Platforms can contribute and on which they can collaborate with the other existing initiatives. TEEBAgriFood business platforms should share information on: the valuation of health impacts arising from unhealthy diets, or arising from agricultural impacts on air and water quality and vector-borne diseases, on impacts of GHG emissions, and on food waste, as areas of key transformation potential.

Given the burgeoning landscape of business-specific or business led initiatives, it will be of utmost importance for TEEBAgriFood Business Platforms to clearly delimit their added value and contribution. In this regard, and as highlighted earlier, the focus of TEEBAgriFood on addressing both ecosystem health and human health impacts and dependencies of eco-agri-food systems adds a specific perspective to the current landscape. No other initiative is highlighting these important dimensions in a systematic way and this could be a unique selling point of a, for instance, “TEEB Global Food and Health Partnership”. It will be crucial, though, to engage in early dialogues with potential members of TEEBAgriFood business platforms to assess the different options for their aims, structures and added value. This would highly increase their potential for success.

10.3.4 Publishing a Food Atlas

TEEBAgriFood’s theory of change allocates an important role to the consumers in the effort to attain transformations in the eco-agri-food system. Hence, targeted engagement with consumers is needed and specific communication strategies will contribute to this. Bolton (2017) emphasizes the need to “turn problems into issues” when seeking change. While big problems (an unsustainable eco-agri-food system) garner attention, they might appear too big to be addressed. According to Bolton, breaking down problems into “solvable issues” is what makes the difference. Developing adapted communication strategies on selected findings of TEEBAgriFood targeting consumers represents another promising engagement strategy.

A communications tool that has proved to be successful in reaching out to the public has been the production of a series of “Atlases”. More specifically, the Meat Atlas (Heinrich Böll Foundation and Friends of the Earth Europe 2014), the Soil Atlas (Heinrich Böll Foundation and the Institute for Advanced Sustainability Studies 2015) and the Ocean Atlas (Heinrich Böll Foundation and the University of Kiel’s Future Ocean Cluster of Excellence 2017) cover topics related to these issues in a concise, easy to read and easy to understand language, and include targeted infographics for highest comprehensibility impact. The Meat Atlas also includes a “hotspots” feature, highlighting issues in specific geographic areas. The aim of these atlases is to provide information on which people can base decisions affecting their behaviour towards these resources. For example, the Soil Atlas focuses on raising public awareness on the critical – and underappreciated – role of soils in people’s daily lives, including on food production and wider ecosystem services. The Ocean Atlas also aims to stimulate a broader social and political discussion about the meaning of the ocean as an important system and the possibilities for protecting it. All three atlases have met with strong public attention and led to high media interest - currently, the Soil Atlas is in its third edition and the Meat Atlas is in its sixth edition. Building on the successful publication of the Meat Atlas, the Soil Atlas and the Ocean Atlas, a Food Atlas will illustrate easy to understand information, highlighting key points on food and food production as it relates to impacts on the different capitals that are part of the eco-agri-food systems.

Publishing a Food Atlas capitalizes on the momentum afforded by growing consumers’ awareness of the impact of food on human health and on the environment. As consumers are increasingly becoming mindful of what they eat, where it comes from and how it is produced, they have a critical role in the transformation of the eco-agri-food system, because they can be drivers of change. Consumer preferences can influence decisions taken along the length of the food value chain; hence the more knowledge consumers are armed with, the more leverage they can exert. Based upon the TEEBAgriFood Evaluation Framework, and using the successful Meat, Soil and Ocean Atlases as models, the publication of a Food Atlas would provide consumers with information about the eco-agri-food complex by addressing selected aspects of these systems making use of high-impact infographics and other communication tools to explain the eco-agri-food system in an easily comprehensible way, using language targeted to the broader public. It will provide an overview of the main issues, the global interconnectedness of production models, the nexus between different capitals (social, economic, environmental) and how these can be reflected in true costing of produce and products at the farm gate. The atlas will convey the strong message that the choices made by consumers in their everyday life matter for one's health and for the health of the planet.

10.4 NEXT STEPS: DEVELOPMENT OF FURTHER ENGAGEMENT STRATEGIES FOR THE SUSTAINABILITY TRANSFORMATION OF THE ECO-AGRI-FOOD SYSTEM

TEEBAgriFood was not designed to be a static, stand-alone initiative. It connects to existing processes, engages with partners, builds upon sound science and evolves in pace with advances in knowledge. TEEBAgriFood seeks practical application of its results with wide array of relevant stakeholders. The purpose is to support multi-stakeholder processes aimed at a transformation of the eco-agri-food system. This chapter makes the case for the need for the innovative approach of TEEBAgriFood to find its way into the core of the current landscape of initiatives aiming towards more sustainable eco-agri-food systems. It also acknowledges that key actors and decision-makers will not automatically reach out and engage with or use the TEEBAgriFood Framework or its outcomes. This implies the need to clearly spell out the uses and benefits of TEEBAgriFood and proactively engage with other actors. TEEBAgriFood's Evaluation Framework adds to existing knowledge by recognizing agriculture as a supplier of food and raw materials but also as a supplier of employment, as a central determinant of the well-being of rural poor, and as a cultural activity embedded in everyday life. It thereby provides a more holistic understanding of eco-agri-food systems. It also establishes the linkages to human health, thereby providing a link to another range of actors and processes to support change in the eco-agri-food system. TEEBAgriFood also helps to reach out to a broad range of constituencies and supports identifying strategic interventions and setting priorities. Actors aiming to engage with and use TEEBAgriFood products are not starting from scratch. There are myriad international agreements, initiatives, platforms and projects that TEEBAgriFood can contribute to and learn from. There is also an increasing recognition that "business as usual" in agricultural production and agricultural production systems is no longer ecologically, socio-culturally or economically sustainable.

To transform learning into action, interlinkages and synergies between varied initiatives and processes outlined here need to be put in practice and exercised is a more active and systematic way. For this, the chapter outlines four engagement strategies according to its theory of change and tailored to the needs of different actors in the previous sections: supporting the integrated implementation of Agenda 2030; financing sustainable food systems; establishing business platforms; and publishing a Food Atlas. To begin with, the 2030 Agenda offers a strategic window of opportunity since the transformation implied by the SDGs is very much in line with TEEBAgriFood's foci. The 2030 Agenda can act as a strategic entry point, as an internationally agreed reference that all actors can use to call for more ambition in changing our eco-agri-food systems. At the same time, if eco-agri-food systems are sustainably governed, they would be contributing to the achievement of a substantial number of targets and goals, thus emphasizing the pivotal role of eco-agri-food systems to sustainable development in general. Financing of such an integrated agenda needs to go beyond financing agricultural production only. The Addis Ababa Action Agenda provides the relevant framework for the design of more relevant financing tools. Countries designing their financing strategies for sustainable development benefit from TEEBAgriFood, as it supports priority setting in the design of financing schemes. Business-centred multi-stakeholder platforms will contribute to similar, existing activities by systematically sharing information emerging from TEEBAgriFood's products; in addition, they will provide a space for cooperation and create opportunities for business actors to personify the change towards sustainable eco-agri-food systems. In this sense, an early dialogue with potential members of such Business Platforms to assess the different options for their aims, structures and added value, and is highly recommended. Finally, a Food Atlas will illustrate easy to understand information, highlighting key points, on food and food production as it relates to/impacts on the different capitals that are part of the eco-agri-food systems.

The four strategies presented in this chapter are non-exhaustive and are intended to be examples of how the results of TEEBAgriFood can be used to support transformations in the eco-agri-food system. These strategies aim to increase the applicability of the TEEBAgriFood Framework and outcomes and the likelihood of involvement by key actors. TEEBAgriFood's learning process is not linear and should be iterative. Therefore, it is important to develop new and adapt existing strategies further to apply the TEEBAgriFood theory of change to the specific stakeholders/processes. Equally, it is of crucial importance to begin implementing and supporting all or a combination of these strategies in order to increase TEEBAgriFood's contribution towards sustainable eco-agri-food systems.

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ANNEX 1

HOW CAN ONE USE THE TEEBAGRIFOOD EVALUATION FRAMEWORK TO ASSESS AN ECO-AGRI-FOOD SYSTEM?

Why use the TEEBAgriFood Evaluation Framework?

Most current assessments of agricultural and food systems are partial and ignore a number of important relationships that eco-agri-food systems have with our economy, society, environment, and health. Examples of partial assessments include farm level assessments of productivity on the basis of yield per hectare only or assessments of environmental efficiency that cover the agricultural production chain but focus only on water or energy use. Such assessments, while clear in scope, leave out broader issues of sustainability and equity that are fundamental considerations in assessing food systems.
Thankfully, discussion is growing around new approaches to assessing eco-agri-food systems including the use of sustainability indicator sets, the measurement and valuation of ecosystem services as inputs to food systems, and the assessment of the connections between food and population health. The perspective of the TEEBAgriFood Evaluation Framework is that these types of approaches need to be integrated in order to better inform policy decisions. Assessments that are context specific and which consider a comprehensive set of interactions, as described in the Framework, will ensure that decision making about food systems captures all material interactions between environment, economy, society, and health and covers interactions from the farm to household consumption.

What does the Framework include?

The Framework includes four elements - stocks, flows, outcomes and impacts - which capture the set of interactions (see **Figure 6A.1**). The stocks of eco-agri-food systems comprise the four different "capitals" – produced capital, natural capital, human capital and social capital. These stocks underpin a variety of flows encompassing production and consumption activity, ecosystem services, purchased inputs and residual flows. The dynamics of an eco-agri-food system lead to outcomes that are reflected in the Framework as changes in the stocks of capitals, both quantitatively and qualitatively. In turn, these outcomes will have impacts on human well-being.

By providing key definitions and associated measurement concepts and boundaries, the TEEBAgriFood Evaluation Framework establishes what aspects of eco-agri-food systems may be included within a holistic evaluation. The chapter does not focus on how assessments should be undertaken, nor does it prescribe methods for assessments. The choice of methods will depend on the focus and purpose of any given assessment, the availability of data, and the scope of analysis.

What is the purpose and role of the Framework?

With these considerations in mind, the Framework identifies and characterizes all relevant elements of our eco-agri-food systems. Of course, eco-agri-food systems are heterogeneous with significant variation in terms of types of outputs, the nature of production systems and value chains. Further, there will be different purposes and perspectives for each assessment. By way of example, while health impacts at consumption stages for corn produced for corn syrup may be material, this would not be the case for corn produced for ethanol for use in biofuel production. Thus, not every possible combination of elements covered by the Framework will be relevant and material in every assessment.

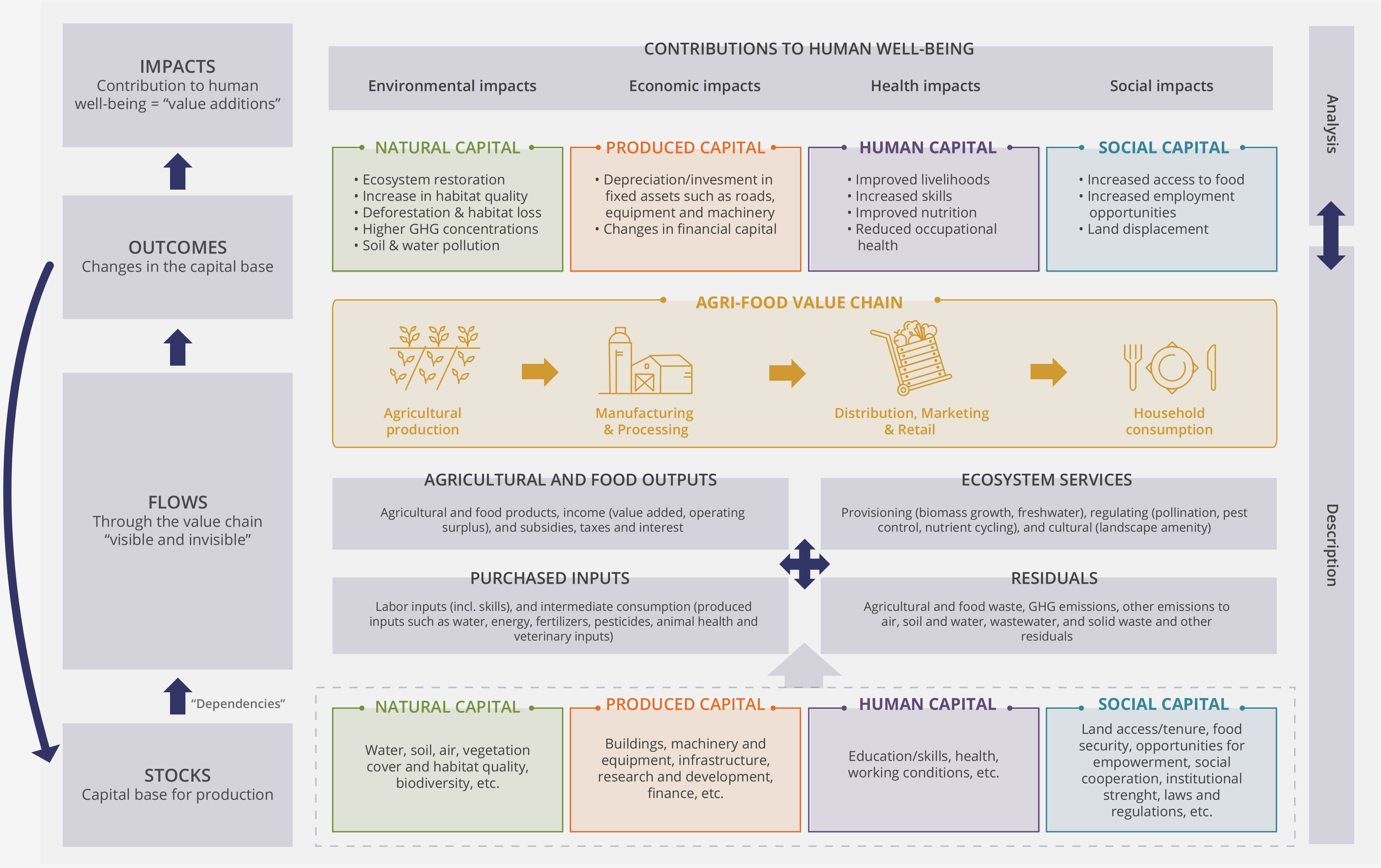
The Framework has thus been designed to provide broad categories of all interactions that may exist within a given eco-agri-food system. This provides a clear and common starting point for all assessments as they work towards identifying the elements that are most material in their context.

While all assessments will have somewhat different coverage, it is also expected that all TEEB AgriFood based assessments have the following features. They should:

- be broad and systemic in nature,
- reflect the contributions of all four capitals and
- examine connections along the full value chain, including assessing the impacts of food consumption on human health.

If these three features cannot be demonstrated, then the assessment would be considered a partial assessment and not consistent with the spirit of the TEEBAgriFood project.

Figure 6A.1 Elements of the TEEBAgriFood Evaluation Framework (Source: authors)



How can the Framework be used for an evaluation or a study?

To demonstrate how the Framework may be used, the following steps may be followed:

1. **Determine the purpose of evaluation.** The purpose of the evaluation exercise may differ within and across groups such as researchers, businesses, or consumer groups. A clear articulation of purpose should be used to scope an assessment.

2. **Determine the entry point and spatial scale of analysis.** The entry point would depend on the research interest or focus of the study. Relatedly, appropriate spatial boundaries would need to be defined – within or across regions, countries etc.

3. **Determine the scope of the value chain under analysis.** This requires the researchers to understand the system and bring together relevant literature and sources to support their description of the value chain – from production to consumption.

4. **Determine the stocks, flows, outcomes and impacts most relevant for the purpose of the study.** The relevant aspects that should considered through literature review and research are:

    - At each and every value chain boundary, identify the flows outlined in Figure 6A.1. It is important to understand that these flows can help identify pathways through which the four capitals contribute to agri-food value chains, and how in turn agri-food value chains may impact the capital stocks. These may include waste or emissions generated along the way. This of course requires certain level of knowledge and research of the given system in question.

    - At each and every value chain boundary, identify the social, produced, natural, and human capital related outcomes of the system (Table 6A.1 provides some examples). This of course requires certain level of knowledge and research of the given system in question.

    - Evaluation of these two aspects requires an understanding and mapping of the spatial scales at which these interactions are happening – ecosystem services used at the farm level may be generated beyond the farm, for example. Similarly, health outcomes of a particular food product may happen well beyond the farm, especially if there is international trade.

    - Given these considerations, the assessment must identify the impacts that it is choosing to address and the ones it is excluding, and provide appropriate reasons.

5. **Select evaluation techniques.** While the first four steps provide the framing and scope of the evaluation, the next step is to choose the techniques that would help one assess and measure the interactions within a given system. For TEEBAgriFood, the focus is on assessing impacts as contributions to human well-being. Other evaluation methodologies may include life cycle assessment and value chain analysis, and various modelling tools and techniques including partial and general equilibrium models and system dynamics.

6. **Collecting data and undertaking the evaluation.** Once the context and methods for evaluation are set, efforts can be made to collect data. While data availability can be an important factor in defining the scope of assessments, by completing steps 1-5 prior, the implications of lack of data can be understood and can provide motivations for identifying and filling information gaps.

7. **Reporting and communicating findings.** Communicating the results of the evaluation exercise should be seen as an essential part of the process. Particular note should be taken of the need to develop a range of outputs to suit different audiences including politicians and business leaders, technical experts, farmers and local communities and the media.

To support the application and implementation of the Framework and the associated discussions among stakeholders, it may be useful to use the tables and text from section 6.3 of the chapter that explain the various components of the Framework. With this in mind, the table below provides a stylised version of the Framework in the form of a checklist that can be used by researchers and decision makers to consider the relevant interactions and to ensure awareness of those aspects excluded from an assessment.

Table 6A.1 comprises two main sections (i) stocks/outcomes (changes in capital stocks) and (ii) flows. Several of these elements may be measured differently – for example, in qualitative, quantitative or monetary terms. Impacts (value addition) elements are excluded from this table since the scope of measured impacts will relate directly to the scope of capital stocks, outcomes, and flows that are included in an assessment. The methodologies for assessing impacts are presented in the TEEBAgriFood ‘Scientific and Economic Foundations’ report, Chapter 7.

It is important to note that several of these elements would require a more detailed description and measurement depending on the scope and context of the assessment being conducted. For example, depending on the assessment, water may include coverage of both surface and ground water resources. Furthermore, quality indicators of water may include several other elements such as habitat quality or nutrient profile. Finally, it is not always the case that all components receive the same type of evaluation and measurement. Thus, in using the table to assess the coverage of an assessment, it will be relevant to distinguish as to whether a component is being assessed descriptively, quantitatively or in monetary terms.

How does the Framework guide researchers, decision-makers (public or private), local communities, farmer groups and other users?

Utilising a comprehensive and universal Framework provides a common basis to compare assessments, a tool for decision-makers to understand what information is missing, and a means to identify areas of further research.

Table 6A.1 Sample checklist to assess coverage of a given eco-agri-food system application (Source: authors)

Example of a checklist to assess coverage of a given eco-agri-food system						
			Value chain			
			Agricultural production	Manufacturing & processing	Distribution & marketing	Household consumption
Stocks / Outcomes (change in capital stock)						
	Natural capital	Water (incl. quality, quantity)				
		Soil (incl. quality, quantity)				
		Air				
		Vegetation cover and habitat quality				
		Biodiversity				
		Other				
	Produced capital	Buildings				
		Machinery and equipment				
		Infrastructure				
		Research and development				
		Finance				
		Other				
	Human capital	Education / skills				
		Health				
		Working conditions (decent work)				
		Other				
	Social capital	Land access/tenure (private, public and communal)				
		Food security (access, distribution)				
		Opportunities for empowerment (gender and minority)				
		Social cooperation (incl networks/unions)				
		Institutions				
		Laws and regulations (e.g. child labor)				
		Other				
Flows						
	Agricultural and food outputs					
		Agricultural and food products				
		Income: value added, operating surplus				
		Subsidies, taxes and interest				
	Purchased inputs					
		Labour inputs (incl skills)				
		Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health and veterinary inputs)				
	Ecosystem services					
		Provisioning (e.g. biomass growth, freshwater)				
		Regulating (e.g. pollination, pest control, nutrient cycling)				
		Cultural (e.g. landscape amenity)				
	Residuals					
		Agricultural and food waste				
		GHG emissions				
		Other emissions to air, soil and water				
		Wastewater				
		Solid waste and other residuals				

Since it includes all categories of material interactions in a given food system, the Framework can offer entry points to many people – for example, researchers focusing on social impacts of food systems, can use social capital related outcomes as a starting point, and then make linkages to the other three capitals. Similarly, decision-makers can start at the economic elements, but then identify how these may be related to other capital stocks and flows. The Framework can also help decision-makers quickly identify any blind spots in the information base used to support decision-making. In essence, no matter what the starting point or purpose, the Framework can allow researchers to contextualise their assessments within the broader set of interactions that their food system has. This not only brings transparency to their assessments, but also highlights the opportunities to link their work with other research.

The TEEBAgriFood Framework can also be a starting point for identifying the material elements of particular systems, and thus can lead to the development of guidelines on comparable assessments. For example, similar firms, in terms of size and products, in the food and beverage sector could use this Framework to identify the main impacts and dependencies of their sector's operations. Similarly, organisations such as farmer cooperatives, consumer protection groups and local governments could elaborate the impacts and dependencies most relevant from their perspective. We encourage the adoption and adaptation of the Framework by diverse groups, and hope that over time, sector specific guidelines can emerge from the TEEBAgriFood Framework.

Further, the Framework is intended for use in an interdisciplinary manner, where the questions to be analysed, the options to be compared, and the scale, scope, and relevant variables included are determined in an open and participatory way. This engagement should occur before the appropriate assessment and valuation methods are implemented.

Overall, the Framework also allows for a broadening of our understanding and conversations around agricultural and food systems. Our aim is that international policies and targets increasingly begin to recognize the interlinkages, in terms of impacts and dependencies that food systems have with our economies, societies, health, and environment. In this task, using the Framework and its language can allow for the next generation of agricultural and food research to provide a more comprehensive basis for decision-making.

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