Sustainability Science in a Global Landscape

Dignity / People / Prosperity
Planet / Justice / Partnership

A report conducted by Elsevier
in collaboration with SciDev.Net

Executive Summary Sustainability Science in a Global Landscape

2015 is a key year for sustainable development. Sustainability as a scientific endeavor requires broad understanding of the interconnections in our global environment. It is not surprising then, that, several development initiatives and large-scale, multi-stakeholder events are taking place to discuss international developments goals. The United Nations (UN) will adopt the post-2015 sustainable development agenda with the Sustainable Development Goals (SDGs) at the UN headquarters in New York this September, following on from the UN Millennium Development Goals (MDGs). In addition, international climate negotiations at the Conference of the Parties (COP21) will take place in Paris in November, where international agreement on the reduction of greenhouse gas emissions will be sought.

Science, technology and innovation have long been recognized as the basis for socioeconomic development. They are also core contributors to sustainable development and to meeting the SDGs. The UN has called for a "seat for science" on the High-Level Political Forum that deals with the UN's sustainable development agenda, to ensure that "science is not just an observer but an advisor to policymakers."[1] This report is part of a broader, on-going effort to provide more evidence and analysis on the role of science, technology and innovation in the global agenda of sustainable development.

This report examines the status of sustainability science as a research field. Throughout the report, we view "sustainable development" as a term that covers the research, programs and collaborative efforts that contribute to sustainable development, and "sustainability science" as the research that supports and drives sustainable development. Examination of the corpus of sustainability science may provide indicators of society's progress towards the goal of sustainable development itself.

The report focuses on three topics:

→ Research output and citation impact: How many publications are produced in sustainability science? How fast does the research output grow? Are the publications impactful, as indicated by field-weighted citation impact (FWCI)?

→ Research collaboration: To what extent is the research in sustainability science internationally collaborative? Do developed and developing countries partner on the research in this field? To what extent is the corporate sector involved?

→ Interdisciplinary research (IDR): What percentage of the research output in sustainability science is interdisciplinary? Which topics are the most interdisciplinary?

Methodology

This report uses the Scopus abstract and citation database to give an overview of the development of sustainability science as a research field. Six themes within sustainability science – *Dignity*, *People*, *Prosperity*, *Planet*, *Justice*, and *Partnership* – encompass the UN's 17 SDGs. Field experts were invited to compose lists of keywords that were used to search for the relevant publications in each theme, and to validate the search results.

The bibliometric analysis was then combined with qualitative research through interviewing key experts in the field. The interviews put the bibliometric results in the larger context of sustainability science as a vehicle to achieve sustainable development goals.

Key findings

1) Sustainability science is a field with a high growth rate in research output

Sustainability science is growing at a tremendous rate. In 2009 the total research output of the field was 56,390 and this increased to 75,602 in 2013. This results in a compound annual growth rate (CAGR) of 7.6%, almost twice the average growth rate of all publications in Scopus over the same period. This implies that even though sustainability science contributes to around 3% of the world's publications, it attracts both an increasing number of researchers and attention from funders.

1 See the UN policy brief at *https://en.unesco.org/un-sab/sites/un-sab/files/Final_SAB_PB_MOI.pdf*, and more information at *http://www.asianscientist.com/2015/07/features/unesco-3-5-gdp-sti-spending/*

The countries with the largest research output in sustainability science are the USA, the UK, China, Germany and Australia (Figure E.1). They produced 31.6%, 10.9%, 9.3%, 6.2% and 5.5% of all publications in sustainability science in the period 2009-2013, respectively. China has the highest growth rate in research output in this field among these five countries: the number of publications from China more than doubled between 2009 and 2013.

The largest and fastest growing of the six themes is *Planet* (Figure E.2). In the period 2009-2013, the research output of this theme increased from 23,015 to 34,501, resulting in an annual growth rate of 10.7%.

Countries have different focuses on the six themes. The USA has a clear focus on the theme *People*, with a large number of publications and a high level of research activity. China and Germany's sustainability science landscape is dominated by the theme *Planet*, and both countries have a small number of publications on the other themes.

2) Research output in sustainability science attracts 30% more citations than an average research paper

The FWCI of publications in sustainability science in the period 2009-2013 is 1.3 – 30% higher than the world average of 1.

Switzerland has the highest FWCI among the top 15 countries with the most significant output in this field (2.35 in 2013). It is followed by Sweden (2.23) and the Netherlands (2.21). India, Brazil and China display a relatively low citation impact below or around the world average of 1.

The theme *Planet* leads all other themes in FWCI (Figure E.2). Throughout the period it remains stable at around 1.50. Meanwhile the theme *Prosperity* has the highest growth in the FWCI of its publications, increasing from 1.10 in 2009 to 1.18 in 2013.

3) Research in sustainability science is highly collaborative

Research in sustainability science is increasingly international. As an example, the USA's proportion of international collaboration increased from 26.5% of its research output in this field to 32.9%.

For countries such as the UK and Germany, around half of their publications in sustainability science are joint efforts by researchers from different countries. Many countries, in particular China and Japan, collaborate much more intensively in sustainability science than overall.

However, the level of collaboration between developed and developing countries in sustainability science is still low. Most of the collaboration between them occurs between high-income and upper-middle-income countries. For low-income countries, collaborative publications with developed countries contribute to a large percentage of their research output in sustainability science, suggesting the importance of these types of collaborations as one means to to help strengthen their research capacity.

In the global research network in sustainability science, Africa is well connected to the USA, Canada and West Europe, where South Africa and countries in East Africa are the research hubs.

4) Sustainability science is less interdisciplinary than the world average

On average, 6.7% of sustainability science publications in the period 2009-2013 belong to the world's top 10% most IDR publications. This number is lower than the world average of 10%, indicating that research in sustainability science is less interdisciplinary than the world average.

However, the percentage is growing. Across the world, we see an increase from 6.1% to 7.1%. Most of the top 15 countries with the largest research output (except two, France and Switzerland) show this same growth pattern.

IDR research in sustainability science focuses on a number of topics. They include health and pollution, water and its social and economic implications, and energy, fuels and their economic and environmental impact.

Sustainability science demonstrates great potential through its high speed of growth in research output, high citation impact and its propensity to international collaboration. The field is attracting more attention and interest from researchers, funders and policy makers. The key challenges for the field in the next 5-10 years include maintaining its growth, attracting appropriate funding and talented researchers, integrating knowledge from various disciplines, strengthening connections with developing countries and industry, and using research outcomes to support and influence policy making in sustainable development. This report provides an evidence based framework for understanding sustainability science based on rich data and analysis. We hope the results of the report will contribute to the dialogue between research communities and wider society to address the challenges we face today.

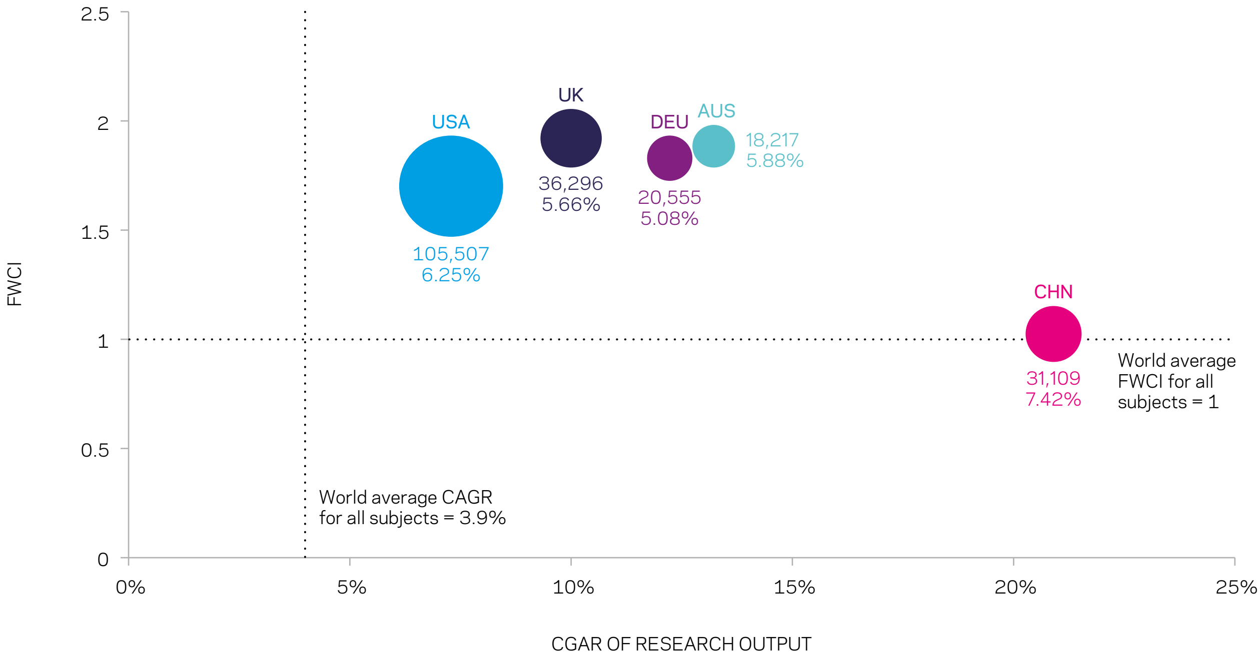

Figure E.1 *— CAGR and FWCI of research output; per country for the top 5 most prolific countries; for sustainability science; for the period 2009-2013. Bubble size denotes the number of publications, and the numbers below each bubble are the number of publications in sustainability science and the percentage of the country's publications in sustainability science in the top 10% IDR.*

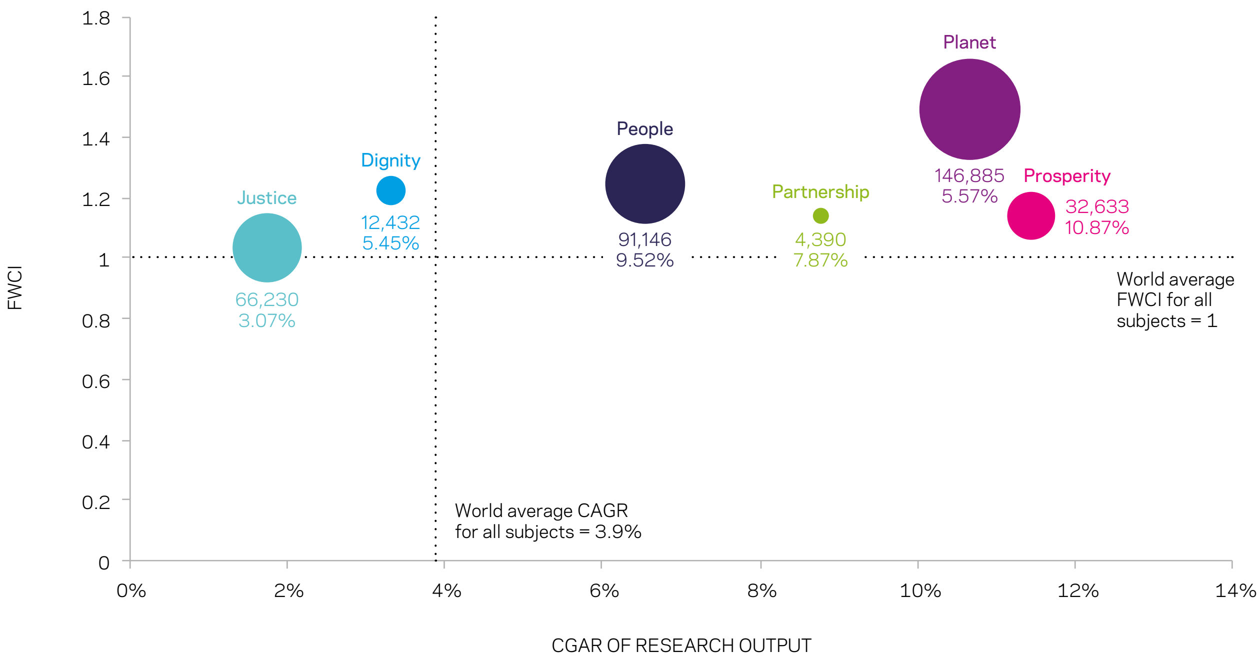

Figure E.2 *— CAGR and FWCI of research output; for the world; per theme for sustainability science; for the period 2009-2013. Bubble size denotes the number of publications, and the numbers below each bubble are the number of publications and the percentage of the theme's publications in the top 10% IDR.*

Key findings

ANNUAL GROWTH RATE IN PUBLICATIONS

7.6%, double the Scopus average growth rate

FIELD-WEIGHTED CITATION IMPACT

30% higher than the world average in the period 2009-2013

INTERNATIONAL COLLABORATION

African countries are well connected with the USA, Canada and Europe

HOT TOPICS IN INTERDISCIPLINARY RESEARCH

Pollution & health, water, and energy & fuels

Foreword

Sustainability Science in a Global Landscape provides a comprehensive picture of the state of sustainability science. It is the forerunner in a series of activities on sustainability science which Elsevier will carry out to commemorate the new sustainable development agenda adopted by world leaders at the Sustainable Development Summit in New York in September 2015.

The 17 new sustainable development goals (SDG's) have been two years in the making and have been ratified by 194 countries with unprecedented input from civil society organizations. The new agenda aims to end poverty, promote prosperity and people's well-being while protecting the environment by 2030. *Sustainability Science in a Global Landscape* provides critical insight into the global research landscape underpinning the SDGs. It encompasses research output, citation impact, research collaboration, and interdisciplinary research, mapping a new research discipline and catalyzing a more informed dialogue between academics, civil society and policymakers on the best way forward.

Perhaps unsurprisingly, the report reveals rapid growth in sustainability science emanating from highly developed countries. But it also shows collaboration between the Northern and Southern hemispheres, highlighting opportunities for lesser developed countries to strengthen their research capabilities through joint projects with peer nations and those in the North. Over the past decade, this has also been a fundamental aim of the Elsevier Foundation, which supports research capacity building grants in developing countries to advance science and health through libraries, training, education, infrastructure, and more.

Collaboration with the UN is a priority for Elsevier and its parent, the RELX Group, which has been a signatory of the UN Global Compact for the past ten years. Elsevier is also a key driver in the Research4Life, a free and low cost access to research program for developing countries which is administered by four UN agencies: the WHO, FAO, UNEP and WIPO. Our sister company, LexisNexis, actively supports the Rule of Law and has helped the UN Global Compact to launch its own "Business for the Rule of Law" Framework earlier this year.

As our annual corporate responsibility report demonstrates, sustainability is deeply embedded within Elsevier. Through the *Sustainability Science in a Global Landscape* report we have analyzed a comprehensive body of global research to draw out the strengths and gaps in the fields of sustainability. We aim to spur a deeper dialogue between all the key stakeholders to advance an understanding of these new disciplines. The challenges are great, but we believe that science and evidence can help us to shape our world for the better for future generations.

Youngsuk "Y.S." Chi
Chairman of Elsevier
August 2015

Partner Foreword

SciDev.Net has been providing original journalism on science for the developing world for the past 15 years. This is a long time in the world of digital journalism but one thing has remained unchanged over that period; at the heart of our coverage is how science and technology can be harnessed for the sustainable development of the planet. In 2010, recognizing a growing convergence of interests in the sustainability agenda, we published a study on science in sustainability. 2015 seemed like a good time to revisit the evolving role of science in sustainable development.

In the ensuing discussion on the post 2015 agenda, there has been a recognition amongst the science community of the need to take a multidisciplinary approach to tackling the world's developmental challenges. This makes for interesting times in science journalism, as the boundaries of methods are pushed and new perspectives on old problems are debated. A stream of coverage has been collected under the theme of "Science and Post -2015" on the site.

This study is a useful first step in helping us to understand the emerging field of "sustainability science". Whilst it is hard to accurately define this dynamic science, the report helps to signal its growing political importance. The results of the research will enable us to map sustainable research – helping us to explore the structural relations and the examples of promising practice which shape and facilitate international research publishing, and in doing so revealing gaps and opportunities. For instance, the report throws up interesting stories like the strength of joint publishing between Kenya and the Netherlands or the diversity of collaborations around health.

Elsevier's Scopus database is one of the most extensive in its field, but even it does not overcome some of the inherent challenges to academic publishing and research practice in developing countries. A set of challenges reflected throughout the report, where the under-representation of authors based in the global South underscores the ongoing need for investment in research infrastructure in low income countries. This is a familiar problem and just as research is exploring new approaches to familiar problems, it is encouraging that publishers such as Elsevier are thinking carefully and creatively about the links between research production and its use.

This is an important point, because the global partnership that underpins the Sustainable Development Goals also applies to those of us working in research. We all have to do our bit. The success of this new "sustainability science" can finally only be judged by whether there is increased uptake of the research by the policy makers who will be largely responsible for achieving the targets of the new goals.

Nick Perkins
Director, SciDev.Net
September 2015

Preface

The unprecedented growth in sustainability science reflects the critical importance of this emerging field. In terms of volume, we are talking about 330,000 articles over a period of five years—quite impressive if you compare this to an annual research output of two million scientific articles. But this exponential growth clearly reflects the size of the sustainability challenges our planet faces today.

None of these challenges are one-dimensional. Energy crises, for example, can only be met if we understand new forms of energy research in relation to urban planning, sociology and social acceptance. For sustainability science to have the biggest possible impact on development, research must cut across many different disciplines.

As members of the academic community, we have asked ourselves how we can best expedite this process. Our core mission is serving research, which in turn fuels innovation, economic growth, improves health care and benefits society as a whole. We see our long-term commitment to new interdisciplinary research as an essential contribution to our information ecosystem. It will help all of us - whether academics, civil society organizations or policymakers - to tackle some of our most significant sustainability challenges.

In terms of publishing actual sustainability research, we are proud to be a leader both in impact and volume of content. But we also go beyond traditional publishing by facilitating face-to-face communication through conferences, collaboration platforms and deep analytics. By using Scopus, our abstract and citation database of peer-reviewed literature, our Analytical Services provide a unique mapping of the research itself, enabling institutions and countries to invest specifically where things are happening, progress is being made and needs are highest.

Sustainability Science in a Global Landscape provides an evidence-based framework for understanding the true interdisciplinary nature of sustainability research. It raises questions on how we evolve our knowledge systems through funding, literature management and education. Through this report, we aim to catalyze our understanding of sustainability science globally and identify opportunities to maximize its impact on development. What about next steps? We'll encourage discussion, listen a great deal and work closely with our partners to reinforce these fast-growing and essential areas of research.

Philippe Terheggen
Managing Director Science, Technology and Medicine Journals at Elsevier
August 2015

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Introduction and Methodology

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SCIENCE AND SUSTAINABLE DEVELOPMENT

On 31 October 2011, the world reached a milestone: the United Nations (UN) Population Fund announced that we had reached a global population of 7 billion.[2] At a press event at UN Headquarters, UN Secretary-General Ban Ki-moon acknowledged the challenges ahead: [3]

"Today, we welcome baby 7 billion. In doing so we must recognize our moral and pragmatic obligation to do the right thing for him, or for her. [...] This is a day about our entire human family. [...] What kind of world has baby 7 billion been born into? What kind of world do we want for our children in the future?"

Baby 7 billion had a one in seven chance of being born into extreme poverty; according to the World Bank, in 2011 just over 1 billion people were living on less than $1.25 a day.[4] Although 1 billion is a staggering number, it shows the significant improvement made in the preceding two decades, nearly half the 1.91 billion people living in extreme poverty in 1990. The targets set by the UN contributed to focusing resources for poverty alleviation programs.

Setting the path to sustainable development

Poverty is considered to be one of the most pressing problems we face today, and for the past 15 years, its alleviation has been one of the focuses of a set of international targets: the Millennium Development Goals.

In 1987, the World Commission on Environment and Development (WCED) published a key report – Our Common Future – in which it defined sustainable development as the "ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." [5]

This definition has been widely used in the years following the report; with increasing awareness of sustainability challenges such as global warming, continued poverty and child mortality, it became a fundamental consideration for world leaders. In September 2000, heads of state gathered at the United Nations headquarters to agree and adopt eight goals related to sustainable development.

The Millennium Development Goals (MDGs) covered peace, the environment, poverty and many other challenges, and the eight goals were to be achieved by 2015. Nearing the end of the MDG period, it is clear that while some goals have been achieved (or are close to being achieved), many are still out of reach.[6]

New goals for a sustainable future

The Rio+20 conference held in 2012 in Rio de Janeiro saw heads of state reconvene and decide how to move forward with these international goals. They agreed to develop a new set of Sustainable Development Goals (SDGs),[7] building on the MDGs and looking towards the future, taking new and emerging challenges into account.

The SDGs have been developed through a process of international collaboration over the past three years, resulting in a proposal by the Open Working Group of 17 goals and 169 targets.[8] These constitute a new set of goals that are actionable and aspirational, intended to help UN member states develop policies and set relevant agendas over the next 15 years.[9]

2 UN News Service Section. 'UN News - As World Passes 7 Billion Milestone, UN Urges Action To Meet Key Challenges'. Available at *http://www.un.org/apps/news/story.asp?NewsID=40257#.VZk-bVwwcSg*

3 See *http://www.unfpa.org/events/day-7-billion*

4 Worldbank.org. 'Poverty And Equity Overview'. Available at *http://www.worldbank.org/en/topic/poverty/overview*

5 World Commission on Environment and Development (WCED), Our Common Future (New York: Oxford University Press, (1987), page 8

6 See *http://www.who.int/mediacentre/factsheets/fs290/en/*

7 Sustainabledevelopment.un.org. 'Sustainable Development Goals: Sustainable Development Knowledge Platform'. Available at *https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals*

8 See Appendix C for a list of the 17 goals. Targets are listed at *https://sustainabledevelopment.un.org/focussdgs.html*

9 Ford, Liz. 'Sustainable Development Goals: All You Need To Know'. The Guardian (2015). Available at *http://www.theguardian.com/global-development/2015/jan/19/sustainable-development-goals-united-nations*

The SDGs will be agreed by 194 member states and launched at the United Nations headquarters in New York in September 2015; they will be in place for 15 years from 1 January 2016. One of the requirements of the goals is that they should be aspirational: to that purpose, targets include ending poverty, achieving gender equity, solving climate change and achieving world peace.

> *"The big point with the SDGs, the big difference with business as usual, is the whole idea of goal based development. Rather than viewing economic, health or demographic change as a system just to be analyzed, we are looking at these as systems to be managed and directed towards particular outcomes."*
>
> *— Jeffrey D. Sachs, Columbia University*

Achieving these substantial goals will not only require international effort, but also collaboration across sectors: non-governmental organizations, governments, companies and research institutions will all play vital roles in reaching the targets set for 2030. Science, technology and innovation in particular have been shown to contribute strongly to sustainable development, and the emergence of a new field – sustainability science – could further extend the role of research in achieving these international targets.

What is sustainability science?

When the MDGs were put in place 15 years ago, science did not factor strongly in discussions around how to achieve the goals.[10] Yet working to solve issues such as poverty alleviation, gender equality and reduced child mortality requires the support of research, and a wave of studies related to sustainable development soon began to appear.

Within a few short years, the field of sustainability science had grown to such an extent that the journal Sustainability Science[11] was launched in 2006, to examine "interactions between global, social, and human systems, the complex mechanisms that lead to degradation of these systems, and concomitant risks to human well-being." The journal aimed to build the new discipline and provide a platform for the kind of complex, interdisciplinary, international research that was becoming more widespread.

According to a paper published in Sustainability Science,[12] the new discipline came to life as a science policy project in preparation for the World Summit on Sustainable Development in Johannesburg in 2002. The authors say that sustainability science "articulates a new vision of harnessing science for a transition towards sustainability and is, thus, an attempt to strengthen the dialogue between science and society."

Similarly, the Initiative on Science and Technology for Sustainable Development says it "seeks to enhance the contribution of knowledge to environmentally sustainable human development around the world."[13] According to Proceedings of the National Academy of Sciences (PNAS), it is "an emerging field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems."[14]

Despite the lack of an agreed definition, sustainability science is generally seen as a group of sciences – often multiple disciplines at a time – addressing common themes in sustainable development, or coming together to support the transition to more sustainable production and consumption models. It considers and rethinks interactions between society and the environment,[15] or science and democracy,[16] for example.

There has been a significant and steep rise in research being published in peer-reviewed journals. A key element of sustainability science is collaboration: many institutions and networks are emerging as strong conveners of researchers, bringing together scientists and technologists to address sustainable development.

How does sustainability science contribute to the SDGs?

Sustainability science is still in its relative infancy, and yet it has already had a huge impact on the research agenda, and aims to inform practical improvements in sustainable development. It builds a bridge between disciplines to address global challenges, and as such is a valuable means for achieving the SDGs.

In her report "Sustainability Science in Europe,"[17] scholar Jill Jäger explains that "sustainability science can be seen as a driver of societal learning and change (SLC) processes," and that it could provide crucial insights for policy makers on complex issues like environmental risk, resource scarcity and emerging diseases. She outlines two main ways in which sustainability science can make a contribution to sustainable development:

- → Dealing with complexity by examining interdependencies rather than single problems
- → Working across disciplines to come up with solutions in a societal context

In theory, it's clear that research plays an important role. But is this what we see in practice?

In 2010, SciDev.net interviewed a number of experts about the role of science in sustainable development, and in particular its impact on progress towards the MDGs.[18] While many agreed there was work to be done, they acknowledged the advancements made, and the importance of science.

On the topic of climate change, Saleemul Huq, senior fellow in the Climate Change Group at the International Institute for Environment and Development in the United Kingdom believes science has had a significant impact. Huq, who has been an author on two Intergovernmental Panel on Climate Change (IPCC) reports, explained: "Science has played an extremely important role because of the issue of the impact of climate change on the potential fulfilment of MDGs."

According to World Food Prize laureate Gebisa Ejeta, distinguished professor of Plant Breeding and Genetics and International Agriculture at Purdue University, science is gaining recognition as a means to achieving sustainable development globally: "For the first time – in a very long time – African leaders have begun to invest in science and are using science as a vehicle for development. And so I really think that the MDGs have provided a mechanism by which leaders have begun to pay attention to the values of science as a solution for a number of problems on the continent."

Sustainability science provides valuable input to sustainable development, the transition to sustainable models and the achievement of international development goals like the SDGs. Research builds knowledge and develops new approaches and perspectives. Through research, academics and policy makers can learn from experiences, and the public can gain an understanding of the challenges and their role in the solutions. Most importantly, sustainability science supports innovation, and by getting involved at a practical level, sustainability scientists are contributing to sustainable development.

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10 SciDev.Net. 'Science: What Has It Done For The Millennium Development Goals?' Available at *http://www.scidev.net/global/health/feature/science-what-has-it-done-for-the-millennium-development-goals--1.html*

11 Sustainability Science, ISSN: 1862-4065 (Print) 1862-4057 (Online), available at *http://link.springer.com/journal/11625*

12 Jerneck, Anne, et al. 'Structuring Sustainability Science'. Sustainability Science 6.1 (2010): 69-82. Available at *http://link.springer.com/article/10.1007/s11625-010-0117-x/fulltext.html*

13 Initiative on Science and Technology for Sustainable Development, available at *http://sustsci.harvard.edu/ists/*

14 See *http://sustainability.pnas.org*

15 Schellnhuber, H. J. 'Earth System Analysis and the Second Copernican Revolution'. Nature 402 (1999): 19-23.

16 Jasanoff, S. and Martello, M.L. 'Earthly Politics. Local and Global in Environmental Governance'. The MIT Press (2004).

17 Jäger, J. 'Vienna Background Paper prepared for DG Research'. (2009).

18 SciDev.Net. 'Science: What Has It Done For The Millennium Development Goals?'. Available at *http://www.scidev.net/global/health/feature/science-what-has-it-done-for-the-millennium-development-goals--1.html*

METHODOLOGY IN DEFINING SUSTAINABILITY SCIENCE

Scope of the study

This report uses the Scopus database to give an overview on the development of sustainability science as a research field. We formed six research themes in sustainability science, following the Essential Elements identified by the UN[20] around which the UN's 17 Sustainable Development Goals (SDGs)[21] are grouped[22]. Throughout the report, we view "sustainable development" as an umbrella term that covers research, programs and collaborative efforts contributing to sustainable development, and "sustainability science" as the underlying research of sustainable development. By forming our themes using the SDGs, we focus on broad aspects of sustainability science that supports sustainable development combining economic, social and environment as three balanced pillars[23]. This report aims to support the dialogue between society and science under the UN SDGs and contributes to the further knowledge building of sustainability science in the global landscape.

Figure I.1 shows the six Essential Elements and how they relate to the SDGs. To define research themes, we mapped the 17 SDGs to the six Essential Elements (Appendix C), resulting in the six themes studied in this report: *Dignity*, *People*, *Prosperity*, *Planet*, *Justice*, and *Partnership*.[24] A few of the SDGs obviously span multiple Essential Elements. For example, Goal 7, "Ensure access to affordable, reliable, sustainable and modern energy for all," is highly relevant to both the economy (*Prosperity*) and ecosystems (*Planet*). It is difficult to draw the border between these two parts of the research covered by Goal 7. We therefore only map Goal 7 to *Prosperity*, as it covers a larger part of the goal. Consequently, the definitions of the six themes only depend on the scope of the SDGs and may differ slightly from the original definitions of the six Essential Elements. The mapping of the 17 SDGs to the six themes affects the distribution of the publications in sustainability science across the six themes. Therefore, we need to take into consideration the underlying SDGs, when interpreting the results of the report.

Defining the six research themes

An essential step in this study is defining the six research themes in sustainability science or, more specifically, finding the publications that are relevant and specific to these six themes.

We adopted a keyword-based approach. Experts in research fields of each of the six themes were identified, utilizing Elsevier's close connections with research communities through journal publishing and engagement with academia (Appendix A), and commented on the keywords that are used in this study. The following steps were conducted:

Figure I.1 *— The six Essential Elements. The figure is reproduced based on Figure 1 in the United Nations' report "The Road to Dignity by 2030: Ending Poverty, Transforming All Lives and Protecting the Planet".*

- We first collected reports relevant to each theme from the World Bank, International Panel on Climate Change and the UN[19].
- We then found the articles referenced in the reports in the Scopus database.
- For each theme, we extracted key phrases from the title and abstract of these articles. The key phrases served as the starting set of keywords for each theme.
- For each theme, we presented the initial set of keywords to the respective independent experts. Based on the experts' feedback, we then selected keywords identified as relevant and added extra suggested keywords.
- We then created six Scopus search queries based on the selected keywords. Summary information based on these queries was presented to the experts for a validity check. The information included a list of top journals, top authors, top institutions and sample articles.

Based on the information provided in the last step, experts suggested changes to the keyword lists. Various rounds of fine-tuning were implemented. For example, for three of the themes we only selected publications that belong to a few of the most relevant Scopus subject areas.[25] We also combined keywords when they were relevant but not specific enough to the theme if used alone.[26] The keywords that were used to identify publications relevant to each theme are listed in Appendix D. The Scopus subject areas that are covered by each theme are presented in Appendix E.

The results of the report were presented in the form of a draft report to experts to validate. In the meantime, we interviewed a number of important players in the field to link the results of the report to their practices and programs. Together with the key findings of the report, their perspectives, questions and suggestions were used to refine the results, build the knowledge to understand sustainability science as a field and to address the key challenges in sustainable development.

Scopus (www.scopus.com)

Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 57 million documents published in more than 22,000 journals, book series and conference proceedings by some 5,000 publishers.

Scopus coverage is inclusive across all major research fields, with 11,500 titles in physical sciences, 12,800 in health sciences, 6,200 in life sciences and 9,500 in social sciences.

Titles that are covered are predominantly serial publications (journals, trade journals, book series and conference material), but considerable numbers of conference papers are also covered from stand-alone proceedings volumes – a major dissemination mechanism, particularly in computer sciences. Acknowledging that a great deal of important literature in all fields, but especially in social sciences and arts & humanities, is published in books, Scopus began to increase book coverage in 2013, aiming to cover 120,000 books by the end of 2015.
Books are however not counted as publications in this report. See the box on page 25 for the list of document types that are counted as publications in this report.

19 These reports only serve as a starting point to provide experts with the first set of keywords. Any report with a long list of relevant references can serve this purpose.

20 Detailed discussion of the six Essential Elements can be found at *http://www.un.org/disabilities/documents/reports/SG_Synthesis_Report_Road_to_Dignity_by_2030.pdf*

21 Information about the 17 SDGs can be found on the United Nations' website at *https://sustainabledevelopment.un.org/sdgsproposal*

22 There are certainly many other ways of defining themes in sustainability science. Kates, R. W. (2011) "What kind of a science is sustainability science?" PNAS 108 (49), 19449–19450 discussed that there are in general two groups of sustainability science papers: those that emphasize research on environment and those that emphasize research on development.

23 See *http://www.un.org/en/development/desa/news/sustainable/sustainable-development-pillars.html* for the discussion about balancing the three pillars.

24 One may argue that defining sustainability science using the 17 SDGs directly without mapping them to the six themes will lead to more detailed information about the different sub-fields in sustainability science. This is true. However, there are large overlaps among the research underlying the 17 SDGs, e.g., between SDG1 on poverty and SDG10 on inequality. It would be difficult to draw the border between the largely overlapped SDGs and find specific keywords that can distinguish the SDGs.

25 For example, for the theme *Justice* only publications that belong to Scopus subject areas social sciences, arts & humanities, multidisciplinary and economics, econometrics & finance are included.

26 For example, for the theme *Planet*, "biodiversity" is combined with "climate," i.e., a selected publication needs to have both words in its title, abstract or keywords.

THE SIX THEMES AND RESEARCH THAT SUPPORTS THE SDGS

The nature of sustainability science means that it has the potential to contribute to virtually every target listed under the 17 SDGs. To understand better what the themes are and what the contribution of sustainability science might look like, it is helpful to look at the keywords that frequently appear and examples of recent peer-reviewed research articles mapped against these themes.

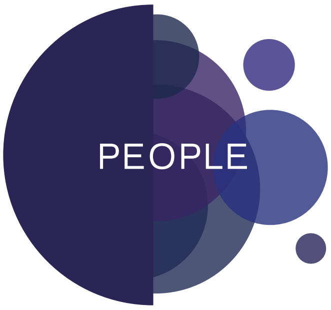
Dignity includes goals to end poverty and fight inequality. In 2003, two-thirds of the population in Sub-Saharan Africa lived in rural areas, and 90% of these people depended on agriculture to make a living. Across Sub-Saharan Africa, one potential approach to alleviating poverty is therefore in agriculture: improvements in this area have the potential to improve food security and lift local smallholders out of poverty.

For instance, a research program in which the National Agricultural Research Organization of Ethiopia collaborated with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) resulted in 11 new and improved varieties of chickpea. Similarly, collaboration between ICRISAT and Tanzanian researchers resulted in the development of two improved, disease-resistant varieties of pigeonpea. In research published in Food Policy,[27] agricultural experts from Italy and the UN in Kenya examined the impact these improved agricultural technologies had on people's welfare in smallholder households in Ethiopia and Tanzania. They looked at household survey data from 1313 smallholder farmers (700 in Ethiopia and 613 in Tanzania).

Results showed that adopting technologies like improved chickpea and pigeonpea varieties can help increase productivity and consumption expenditure, improving the welfare of smallholder households and contributing to poverty alleviation. Despite this, 70% of the households surveyed had not yet adopted the technologies. The researchers suggest that to encourage more farmers to adopt new technologies, access to the seed and information about the technologies is vital.

Figure I.2 - I. 7 *— See word clouds on pages 18-21.*
Top 50 most frequent words in publications for each theme in sustainability science.
The size of the words denotes occurrences of the words in the theme.

Footnotes for pages 18-21 can be found on page 21.



People aims to ensure healthy lives, knowledge and the inclusion of women and children. Health, education and gender equality are the main topics in this theme.

Vaccination helps to ensure healthy lives: it prevents the deaths of millions of people by protecting them from diseases like measles, polio and diphtheria. Access to vaccination is limited in many low- and middle-income countries, and various groups aim to ensure that all children can be vaccinated against preventable diseases.

A supplement of the journal Vaccine[28] was published in 2013, showing the progress towards global vaccination coverage. The Decade of Vaccines supplement includes contributions from more than 100 authors, and highlights strategies to further advance progress on the Global Vaccines Action Plan[29] that was endorsed by the World Health Assembly in 2012. Supported by the World Health Organization (WHO), UNICEF, the GAVI Alliance[30] and the Bill & Melinda Gates Foundation,[31] the plan aims to deliver universal access to immunization by 2020.

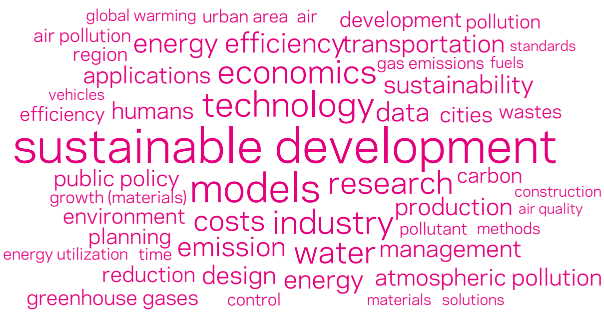
In one article,[32] public health researchers from Europe and the US used mathematical models to predict the number of deaths averted in GAVI-eligible countries. The study revealed that the use of nine different vaccines between 2011 and 2020 is expected to avert 10 million deaths, and measles vaccination is expected to avoid another 13 million deaths. However, the collective knowledge presented in the supplement suggests that protecting the 22 million unvaccinated children in developing countries will require better supply and logistics systems, international cooperation and funding.

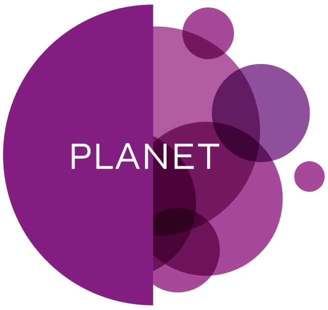
Prosperity sets out targets to grow a strong, inclusive and transformative economy. It is a broad theme that includes research on sustainable economy, cities and urbanization and on resources such as water and energy.[33]

Energy innovation and access to energy are important features of this element. In his book Creativity in Engineering,[34] David Cropley explains that creativity in technology has a positive impact on development: "Economic progress, built on the foundation of technological creativity, has resulted in a rise in living standards; improved nutrition, clothing, housing, health; reduced toil; and reduced disease."

Two of our biggest challenges today – limited natural resources and increasing waste – are being combined to come up with creative new ways of reducing our resource consumption and waste, to increase energy availability and redefine the economy. Researchers looked at a potential reverse energy supply chain in their Journal of Cleaner Production paper,[35] considering a scenario where waste generated in one country produces energy in another, via an emissions trading scheme.

This could go some way towards improving access to energy, which is still a problem in many regions. In Africa, for example, only 26% of households have access to electricity, leaving 550 million people in the continent in the dark. A study in Energy Policy[36] explores the factors that affect the success of energy innovations in Africa, and reveals an "Entrepreneurial Motor of innovation centered on Toyola Limited," a clean energy company that develops new technologies. The study suggests that if this approach is to be modeled, barriers like access to electricity at production plants will need to be overcome, and infrastructure may require improvements.

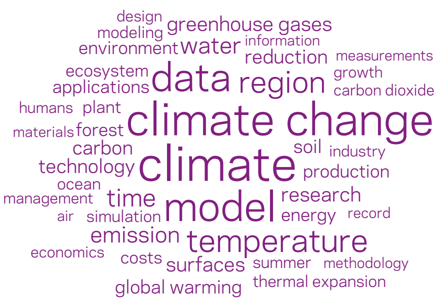




Planet includes goals that aim to protect our ecosystems for all societies and our children. Environmental challenges were among the first to gain attention in the late 20th century, with acid rain and global warming quickly gain importance on the policy and corporate responsibility agendas quickly. The focus has since moved towards climate change and ecosystem services as two of the major issues to address. The ecosystem services model says that ecosystems are vital to our society, providing us with much-needed materials and resources, from water to medicines. Protecting and working with them, therefore, is crucial.

Hydraulic engineering infrastructures are one concern for instance, because they are likely to interfere with the environment. One way to protect ecosystem services is through a Building with Nature (BwN) approach, which enables engineers to build hydraulic infrastructures without damaging the ecosystem. Research published in the Journal of Hydro-environment Research[37] explores the use of the BwN approach, considering a number of examples, including flood protection structures, sand dune replenishment and oyster reefs.

The authors suggest that thinking should start from the natural system, rather than from a design concept, and should consider the interests of different stakeholders. The authors also indicate that engineers need to act more collaboratively, and their involvement should extend beyond the project. And they also should interact more with different groups – BwN requires interdisciplinary work. Doing this would enable engineers to respond to society's need and respond to changing environmental conditions. Furthermore, working with nature in this way could even cost less.



Justice promotes safe and peaceful societies and strong institutions. According to the UN Refugee Agency UNHCR, by the middle of 2014, almost half of Syria's 22 million population was affected by the conflict in the country.[38] There are more than 33,000 asylum seekers and refugees in Syria, mostly from Iraq, and as well as from Afghanistan and Somalia. In August 2014, a further 95,000 people displaced due to the conflict in Iraq traveled across the border and into the Kurdistan region. This is just one example of the many conflicts and wars the world experienced in the recent years.

Millions of people are affected by war every year, and applying justice system to war crimes can help build strong societies again. A paper published in Political Geography looks at the Court of Bosnia and Herzegovina (CBiH) as a case study.[39] Created between 2002 and 2014, the CBiH has had jurisdiction over war crimes trials since 2006. The court's sponsors believe it has made progress "toward achieving justice for the crimes committed during the 1992–1995 conflict in Bosnia and Herzegovina (BiH)," but it also has an additional role: building a sense of Bosnian citizenship.

Qualitative data analyzed in the paper revealed previous tensions between the legal mechanisms and the constitution of liberal democratic citizenship. The court was established as an intervention to these tensions, to show legally guaranteed human rights after the conflict. To achieve this, the court relied on a combination of localized law and public outreach, carried out through civil society. In their concluding remarks, the researchers state "there is a need to engage in actual existing practices of law and citizenship in their plurality, often pursuing seemingly divergent political agendas."

Partnership aims to catalyze global solidarity for sustainable development. Collaboration is a recurring theme throughout the SDGs, and a key aspect of the research that contributes to achieving them. Partnerships between agencies, civil society organizations, companies and research institutions helps unpack a problem and view it from many different angles, resulting in more robust, effective solutions.

In research, projects like Methods and Tools for Integrated Sustainability Assessment (MATISSE)[40] and Assessment of Renewable Energy Technologies on Multiple Scales (ARTEMIS)[41] unite many projects to work together to address different issues.

Resource management involves a number of different parties, and researchers in Malawi used the country's water management approach as an example in their paper published in Desalination.[42] Malawi has experienced significant water scarcity problems, and additional issues with hydropower generation, navigation on lakes and a lack of water supply to towns are all related to poor water management. The researchers conclude that these problems would be prevented by better collaboration and harmonized policies to strengthen water management.

27 Asfaw, Solomon et al. 'Impact Of Modern Agricultural Technologies On Smallholder Welfare: Evidence From Tanzania And Ethiopia'. Food Policy 37.3 (2012): 283-295. Available at *http://www.sciencedirect.com/science/article/pii/S0306919212000176*

28 Available at *http://www.sciencedirect.com/science/journal/0264410X/31/supp/S2*

29 Who.int. 'WHO | Global Vaccine Action Plan 2011 - 2020'. Available at *http://www.who.int/immunization/global_vaccine_action_plan/en/*

30 See *http://www.gavialliance.org/*

31 See *http://www.gatesfoundation.org/*

32 Lee, Lisa A. et al. 'The Estimated Mortality Impact Of Vaccinations Forecast To Be Administered During 2011–2020 In 73 Countries Supported By The GAVI Alliance'. Vaccine 31 (2013): B61-B72. Available at *http://www.sciencedirect.com/science/article/pii/S0264410X12016283*

33 The OECD has conducted various studies related to this theme. See more information at *http://www.oecd.org/greengrowth/sustainabledevelopmentkeyreports.html*

34 Cropley, David. Creativity In Engineering. "Chapter 2 – The Importance of Creativity in Engineering," pages 13–34, available at *http://www.sciencedirect.com/science/article/pii/B9780128002254000021*

35 Bing, Xiaoyun et al. 'Global Reverse Supply Chain Redesign For Household Plastic Waste Under The Emission Trading Scheme'. Journal of Cleaner Production 103 (2015): 28-39. Available at *http://www.sciencedirect.com/science/article/pii/S0959652615001328*

36 Agbemabiese, Lawrence, Jabavu Nkomo, and Youba Sokona. 'Enabling Innovations In Energy Access: An African Perspective'. Energy Policy 47 (2012): 38-47. Available at *http://www.sciencedirect.com/science/article/pii/S030142151200256X*

37 de Vriend, Huib J. et al. 'Sustainable Hydraulic Engineering Through Building With Nature'. Journal of Hydro-environment Research (2014): 159–171. Available at *http://www.sciencedirect.com/science/article/pii/S1570644314000653*

38 United Refugees. 'UNHCR - Syrian Arab Republic'. Unhcr.org. Available at *http://www.unhcr.org/pages/49e486a76.html*

39 Jeffrey, Alex, and Michaelina Jakala. 'Using Courts To Build States: The Competing Spaces Of Citizenship In Transitional Justice Programmes'. Political Geography 47 (2015): 43-52. Available at *http://www.sciencedirect.com/science/article/pii/S0962629815000086*

40 See *http://www.sei-international.org/projects?prid=288*

41 See *http://seri.at/en/projects/completed-projects/artemis/*

42 Chipofya, V., S. Kainja, and S. Bota. 'Policy Harmonisation And Collaboration Amongst Institutions – A Strategy Towards Sustainable Development, Management And Utilisation Of Water Resources: Case Of Malawi'. Desalination 248.1-3 (2009): 678-683. Available at *http://www.sciencedirect.com/science/article/pii/S001191640900650X*

ANALYSING THE IMPACT OF SUSTAINABILITY SCIENCE

As member states prepare to work towards the SDGs, organizations like the Sustainable Development Solutions Network (SDSN) are considering ways of monitoring progress. After 18 months of consultative work with almost 500 organizations and thousands of individuals, the SDSN presented a report to the UN in June 2015 outlining suggestions for indicators that could be used to monitor progress and support the goals and targets.[43] Although there is no single goal related to science and technology, it is so fundamental that the report lists an indicator to monitor research and development:

"Indicator 63: Personnel in R&D (per million inhabitants) Rationale and definition: The fields of science, technology and innovation are key drivers of economic growth and development. Progress in these fields requires trained staff engaged in research and development (R&D). This indicator measures the total number of personnel (researchers, technicians and other support staff) working in research and development, expressed in full-time equivalent, per million inhabitants. This indicator goes beyond technology development, diffusion, and adoption, but is important for achieving many of the SDGs."

Understanding the research being done to contribute to the SDGs is also vital. In an opinion piece for SciDev.net, Erik Millstone, professor of science policy at the Science Policy Research Unit of the University of Sussex, explained: [44]

"It will then be clear that much of the science on particular policy-relevant issues is incomplete and uncertain, and that interpretations of the science are framed by non-scientific assumptions about, for example, what counts as a benefit or as a risk. If some of those assumptions were articulated, then organisations and citizens could better understand and make sense of competing claims. And this will increase the chances of scientific knowledge truly contributing to sustainability."

Analyzing published research also helps provide direction: understanding where gaps exist and identifying opportunities to strengthen collaboration and interdisciplinary research could maximize the impact of sustainability science on the SDGs. This report, therefore, is the first of a series of activities that builds insights in the science of sustainability and identifies the strengths and weaknesses of science for sustainable development. By taking a global view of the sustainability science landscape in the context of the six Essential Elements of the SDGs, the report aims to highlight important cross-country, cross-sector and cross-subject research collaborations that support a post-2015 development agenda.

The present report combines an in-depth analysis of the research landscape in sustainability science, as well as interviews with world leading experts in the area. We are thus combining a quantitative approach – through the analysis of scientific publications as well as a qualitative approach through the use of interviews. The interviews support the quantitative findings and provide a larger context to the study of sustainability science.

We however acknowledge that not all research in sustainability science takes the form of peer-reviewed literature. A reasonable proportion of research outputs are published as reports, policy documents or even media. Extracting the rich information from these types of literature using e.g., Elsevier Fingerprint Engine™[45] is a direction with great potential for future studies.

We also acknowledge that this report is framed around several themes which are necessarily subjective as different themes can be framed and grouped in different ways. The global research landscape is highly dynamic with new fields evolving over time, which creates challenges for the identification of emerging fields and disciplines. Sustainability Science and the themes themselves come out of political discourses and by extension make it challenging to map these onto the research landscape. This exacerbates the dynamic nature of the research landscape.

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43 Unsdsn.org. 'Sustainable Development Solutions Network | Indicators And A Monitoring Framework For Sustainable Development Goals: Launching A Data Revolution For The SDGs'. Available at *http://unsdsn.org/resources/publications/indicators/*

44 SciDev.Net. 'Why Science Is Not Enough For Good Policy'. N.p., 2015. Available at *http://www.scidev.net/global/policy/opinion/science-good-policy-knowledge-sussex.html*

45 See *http://www.elsevier.com/solutions/elsevier-fingerprint-engine*

Chapter 1 Research Output and Citation Impact

This chapter summarizes the findings on research output and citation impact in sustainability science. Additionally, we investigate the research focuses of the most prolific countries, and the top institutions in sustainability science.

1.1 Key findings

RESEARCH OUTPUT

334,019

In total, the world produced 334,019 publications in sustainability science in the period 2009-2013. The volume increased from 56,390 in 2009 to 75,602 in 2013, resulting in an annual growth rate of 7.6%.

FIELD-WEIGHTED CITATION IMPACT (FWCI)

1.30

The average FWCI of the publications in sustainability science was 1.30 in 2013, 30% higher than the world average of 1.

RESEARCH FOCUS

USA: *People*
China & Germany: *Planet*

Countries have different research focuses on the various themes in sustainability science. The USA has the largest number of publications and the highest relative activity index in the theme *People*. China and Germany both show a clear focus on *Planet*.

1.2 Research output

Two groups of countries contribute most significantly to the scientific output worldwide. One group consists of research intensive countries with a high share of world's publications relative to their population share, such as the USA and the UK. The other group consists of emerging countries that have grown their research output rapidly in recent years. Countries such as China and India play an increasingly important role in scientific research; the rapid growth of their research output has changed the research landscape in the past decade.

This general trend in scientific research is also observed in sustainability science. The world produced 334,019 publications in sustainability science in the period 2009-2013 – around 3% of the 11 million publications in Scopus for the same period. We see in Figure 1.1 that research intensive countries such as the USA, the UK, Germany and Australia, and emerging countries such as China, India and Brazil, are all among the top 15 most prolific countries in sustainability science. The USA is well ahead of the other countries in terms of the volume of research output, producing more than 30% of the world's publications in sustainability science (nearly three times as much as the second most prolific country in this area). In 2009, the USA produced 17,945 publications and this number increased to 23,788 in 2013.

The UK and China produced the second and third largest numbers of publications, with 8,645 and 8,298 publications in 2013, respectively. China is approaching the UK rapidly: in 2009, the difference in research output between the two countries was around 2,100 publications and in 2013 this number fell to less than 400.

In fact, China shows the highest compound annual growth rate (CAGR) in publications among the top 15 most prolific countries, at 20.9% (Figure 1.2) – more than double its overall growth rate in Scopus for the same period (9.5%). It is followed by India (18.2%) and Spain (17.0%). The USA and Japan have the lowest CGAR among the top 15 countries at 7.3% and 7.4%, respectively. These CAGRs are still much higher than the countries' overall publication growth in Scopus (2.5% for the USA and 0.5% for Japan).

The average CAGR for the world in sustainability science from 2009 to 2013 is 7.6%. This is almost double the average growth rate of all Scopus publications (3.9%), a strong indication that sustainability science is a fast growing research field that attracts increasing attention and interest from researchers.

Publication counts

We count the following types of documents as publications: articles, reviews and conference proceedings.

Full counting is used. For example, if a paper has been co-authored by one author in the UK and one author in the USA, the paper counts towards both the publication count of the UK and that of the USA. The total count for each country is the unique count of publications.

One publication may belong to multiple themes in sustainability science. The publication then counts toward each theme it belongs to. These duplicates are removed when we count the total number of publication in sustainability science.

Compound annual growth rate (CAGR)

The CAGR is defined as the year-on-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series:

$$CAGR(t_0,t_n) = \left(\frac{V(t_n)}{V(t_0)}\right)^{\frac{1}{t_n-t_0}} - 1$$

where $V(t_0)$ is the starting value, $V(t_n)$ is the finishing value, and t_n-t_0 is the number of years.

"It was surprising to me that the US and Japan are below average in terms of growth rate of publications. That is a concern, countries with relative low growth rate in research output should think about where their investments are going in sustainability science."

— Richard Horton, The Lancet

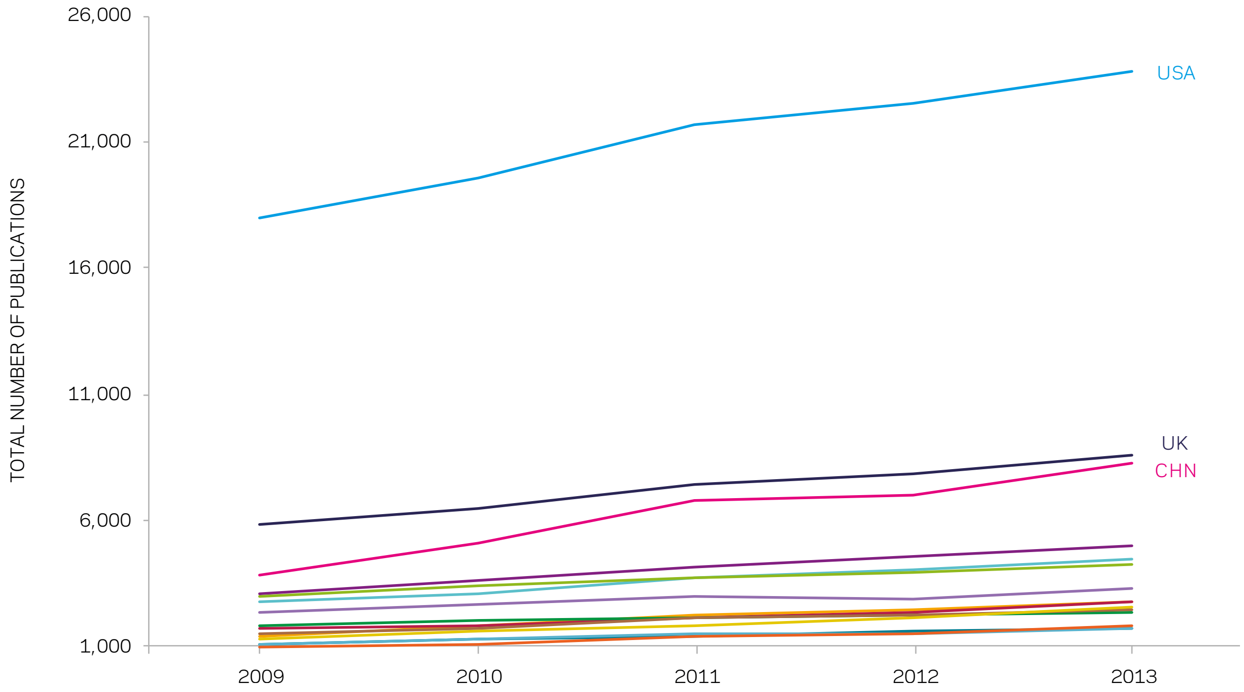
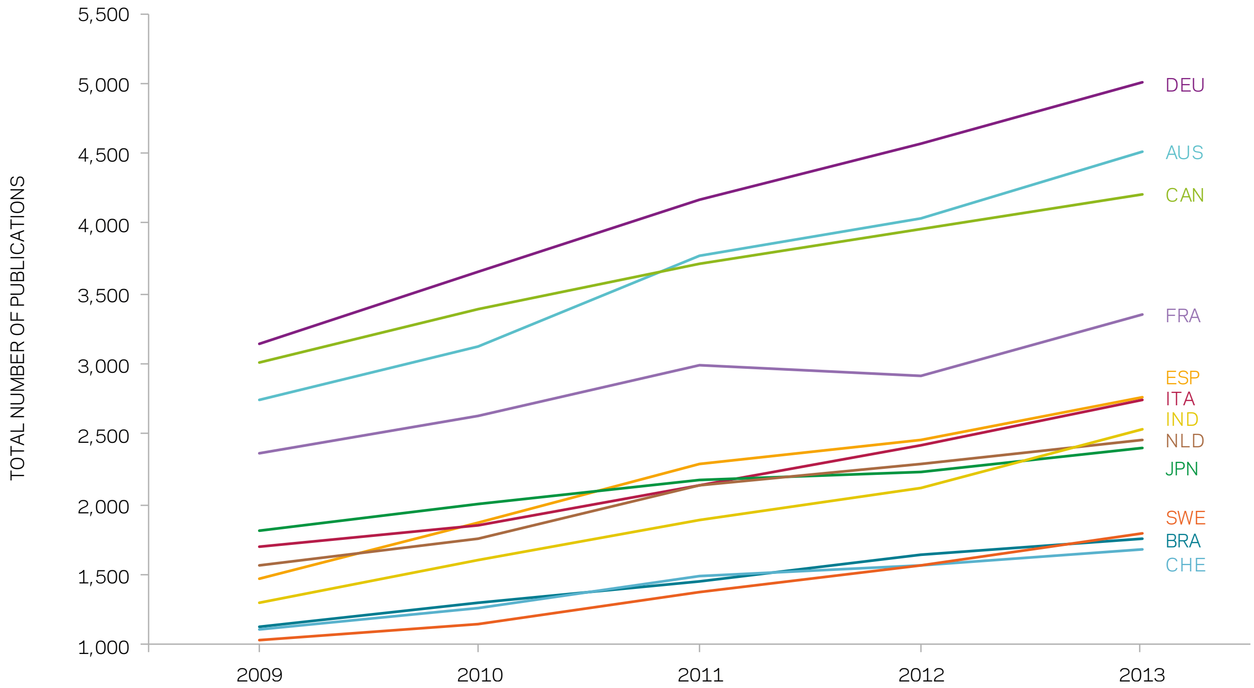


Figure 1.1 *— Total number of publications; per country for top 15 most prolific countries in sustainability science; for sustainability science; per year for the period 2009-2013.*
***a**. Top 15 most prolific countries*



***b**. Top 15 most prolific countries, excluding the USA, the UK and China*

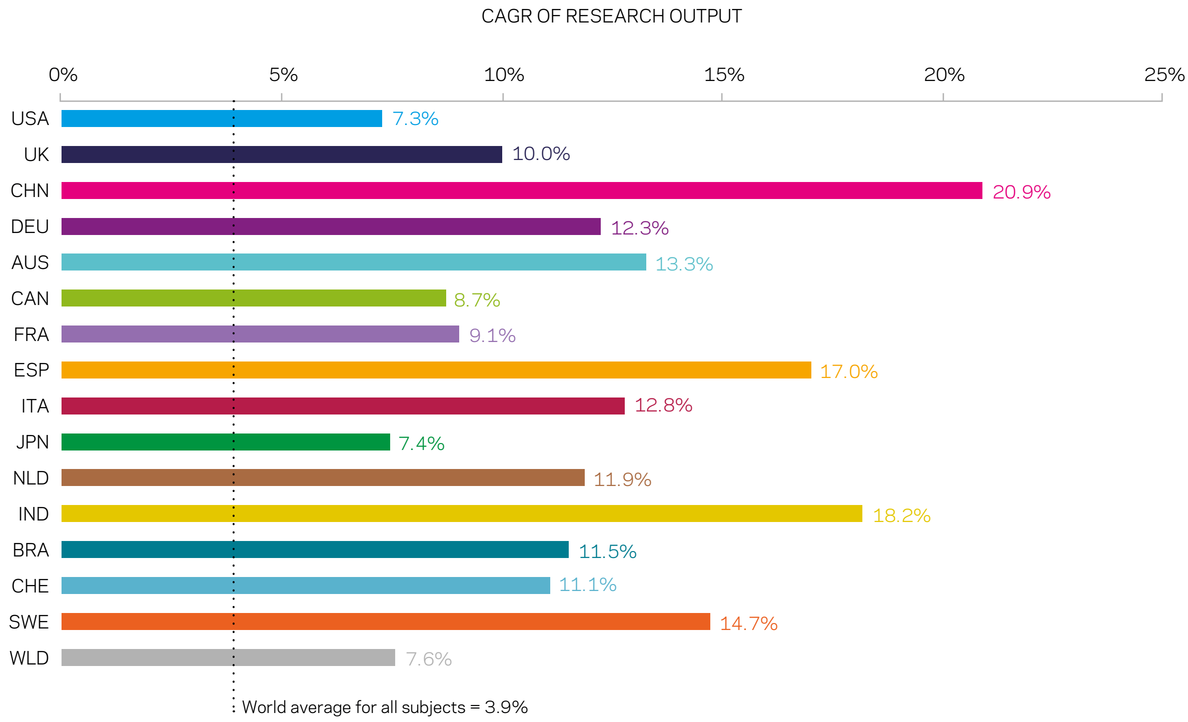


***Figure 1.2** — CAGR of publications in sustainability science; per country for the top 15 most prolific countries in sustainability science; for the period 2009-2013.*

Of the six themes, *Planet* is the largest in terms of the number of publications, with 23,015 publications in 2009 and 34,501 in 2013. *Planet* covers many key topics in sustainability science, such as climate change, natural resources and biodiversity, and attracts significant attention from funders, so it comes as no surprise that it has a large number of publications.

People is the second largest theme, with 91,146 publications in the period 2009-2013. Publications in medicine that are related to the SDG on improving people's health fall into this theme. Medicine is the largest subject area in Scopus, contributing to around 20% of all publications in the database. Only the subset of publications in medicine most relevant to the theme *People* were selected,[46] which seem to increase the volume of research output in this theme.

Justice, *Prosperity* and *Dignity* have 66,230, 32,633, and 12,432 publications in the period 2009-2013, respectively. *Partnership* is the smallest theme, with 4,390 publications in the five-year period. Partnership is key to sustainable development; partnerships were an important outcome of the World Summit on Sustainable Development held in Johannesburg in 2002, with more than 200 partnerships launched during the Summit process.[47] However, most of the partnerships in sustainable development result in development programs, activities and reports, rather than peer-reviewed publications. This is why the theme *Partnership* appears to be small when we focus on sustainability science.

46 Relevance is defined as having keywords that are specific to SDG3 "Ensure healthy lives and promote well-being for all at all ages" and belong to Scopus detailed subject areas that are most relevant to Sustainable Development. See Appendix D for the list of keywords and subject areas.

47 See *http://www.un.org/esa/sustdev/partnerships/brochure_E.pdf*

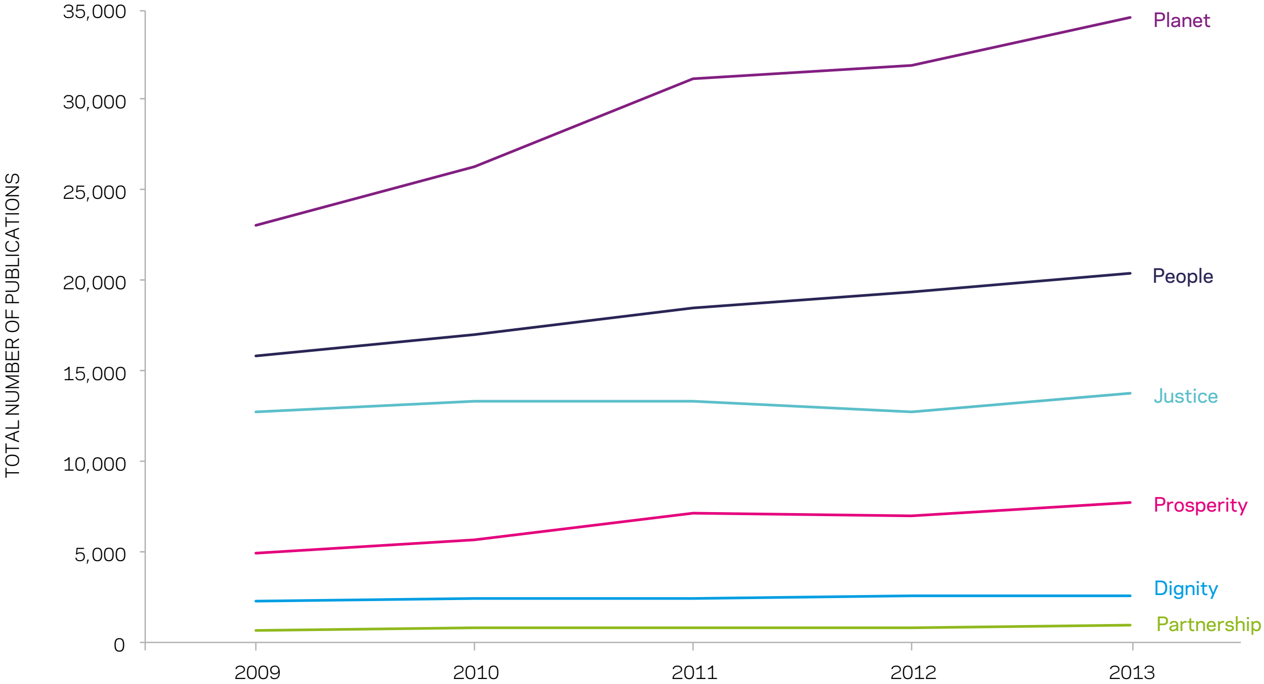


Figure 1.3 *— Total number of publications; for the world; per theme for sustainability science; per year for the period 2009-2013.*

1.3 Citation impact

Researchers, research managers, research funders and practitioners are all seeking to understand the impact of research – a broad concept that covers, but is not limited to, citation impact, usage, social and economic impact. In this report, we focus on the citation impact of research output. We use an indicator called field-weighted citation impact (FWCI) to measure citation impact. It takes into consideration the differences in citing behavior across disciplines, years and towards different document types, and is one of the most sophisticated indicators in the modern bibliometric toolkit.

Publications in sustainability science have a high FWCI: for the period 2009-2013, it is 30% higher than the world average of 1, an indication of high impact of research in this field. The theme *Planet* has the highest FWCI among the six themes, at around 1.50. It is followed by *People* and *Dignity*. *Prosperity* shows the largest increase in FWCI, from 1.10 in 2009 to 1.18 in 2013. Both *Partnership* and *Justice*'s FWCI decreased between 2009 and 2013. In all six themes, the FWCI is above the world average of 1, but the recent decrease in FWCI in *Justice* brings the FWCI in this theme close to the world average of 1.

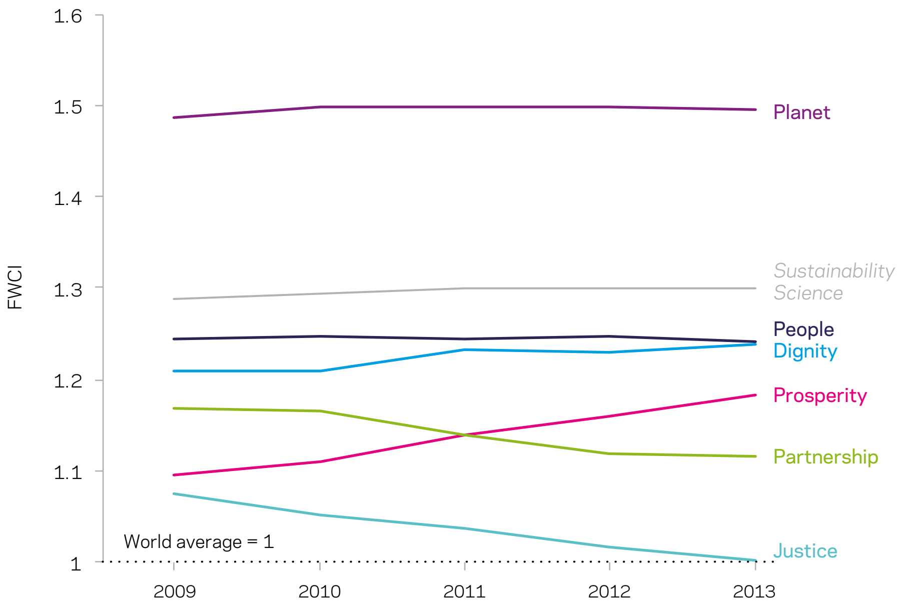


***Figure 1.4** — FWCI; for the top 15 most prolific countries in sustainability science; per theme for sustainability science; per year for the period of 2009-2013.*

Field-weigthed citation impact

Citations accrue to published articles over time, as articles are first read and subsequently cited by authors in their own published articles. Citation practices, such as the number, type and age of articles cited in the reference list, may also differ by research field. As such, in comparative assessments of research output citations must be counted over consistent time windows, and field-specific differences in citation frequencies must be accounted for.

Field-weighted citation impact is an indicator of mean citation impact, and compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review or conference proceeding paper), publication year and subject field. When an article is classified in two or more subject fields, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (reviews typically attract more citations than research articles, for example), as well as subject-specific differences in citation frequencies. FWCI is one of the most sophisticated indicators in the modern bibliometric toolkit.

To count citations, a five-year window is used. For publications in 2009, their citations in the five-year period 2009-2013 are counted. For publications in 2013, their citations to date are counted.

Figure 1.5 presents the FWCI of the top 15 countries' publications in the same chart as these countries' world publication share in sustainability science. Switzerland leads these countries in FWCI: in 2013 its FWCI was 2.35, more than twice the world average. The USA and the UK have both a high FWCI (1.69 and 1.92 in 2013, respectively) and a large world publication share (31.5% and 11.4% in 2013, respectively), confirming their strong positions in this research field. Other research intensive countries, including Germany, Australia, Canada, France and Spain, also have high FWCIs. Germany, Italy, Switzerland and Sweden are successful in maintaining the citation impact of their publications while increasing the volume of their research output.

Japan, China, Brazil, and India have relatively low FWCI among the top 15 countries. India's FWCI is below the world average of 1 in all years in the period 2009-2013. It should, however, be noted that the FWCI of India's publications in sustainability science is higher than that of all of its publications in Scopus: for 2013, the former is 0.96 and the latter is 0.75.

Who are the top contributors to publications in sustainability science? Table 1.1 lists the top five most prolific institutions for each theme. The World Bank produced the largest number of publications for *Dignity*, in line with its mission to fight poverty globally. American universities dominate the top five institutions for *People*, indicating the USA's leading position in this theme. We see three Chinese institutions in the top five for *Prosperity*, implying that China has many research activities on this theme. All top five institutions for *Planet* are large government bodies or national research institutions. They are located in the USA, China, Australia and Spain. For *Justice*, the top five institutions are a mixture of top universities in the USA, the UK and Canada. We see two institutions in Australia among the top five institutions for *Partnership*, an indication of Australia's research strength on this theme.

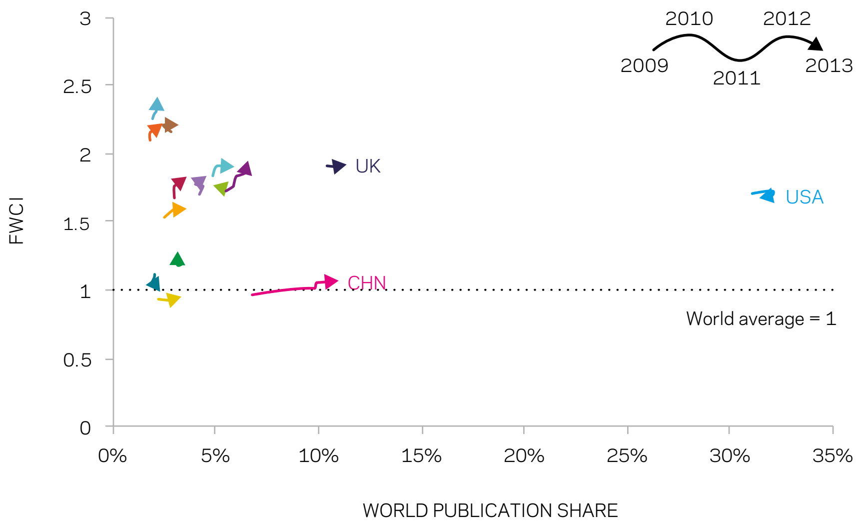
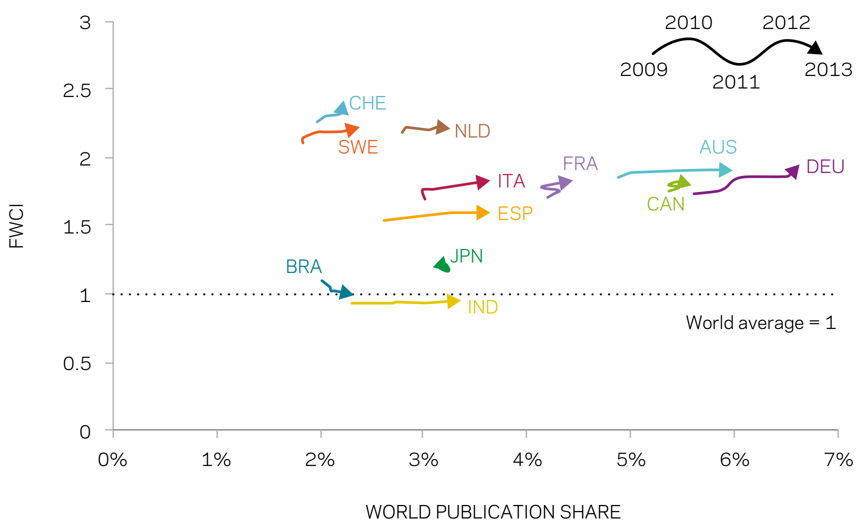


Figure 1.5 *— World publication share and FWCI; per country for the top 15 most prolific countries in sustainability science; for sustainability science; per year for the period 2009-2013.*

a. *Top 15 most prolific countries*



b. *Top 15 most prolific countries excluding the USA*

Table 1.1 *— The most prolific institutions; for the world; per theme for sustainability science; for the period 2009-2013.*

Themes/Institutions	*Publications in sustainability science*	*FWCI*
DIGNITY		
World Bank	208	2.07
Wageningen University and Research Center	131	2.22
University of Oxford	129	2.07
Cornell University	113	3.55
International Food Policy Research Institute	111	2.18
PEOPLE		
Harvard University	2,124	2.28
Johns Hopkins University	1,372	1.90
University of Toronto	1,195	1.72
Columbia University	1,055	1.97
US Department of Veterans Affairs Medical Center	999	1.73
PROSPERITY		
Tsinghua University	289	1.77
Chinese Academy of Sciences	279	1.46
University of California at Berkeley	228	2.42
U.S. Environmental Protection Agency	201	1.19
Peking University	174	2.00
PLANET		
Chinese Academy of Sciences	2,341	1.31
National Oceanic and Atmospheric Administration (NOAA), USA	1,947	2.83
U.S. Department of Agriculture	1,673	2.19
Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia	1,570	2.83
Spanish National Research Council (CSIC)	1,372	2.49
JUSTICE		
University of Oxford	543	1.63
Harvard University	505	2.31
Columbia University	395	1.84
University of Toronto	380	1.22
London School of Economics	345	1.68
PARTNERSHIP		
Wageningen University and Research Center	55	2.17
University of British Columbia	43	4.22
University of Queensland	41	5.03
Harvard University	35	4.15
Griffith University Queensland	31	2.58
World Health Organization	31	2.94

INTERVIEW

Ashish K. Jha

Director, Harvard Global Health Institute;
K. T. Li Professor of International Health and Health Policy,
Harvard School of Public Health;
Professor of Medicine, Harvard Medical School

What do you think of this report?

We have been considering the effectiveness of the Millennium Goals in achieving their objective to focus the minds of policy makers. The question now becomes: how can we translate that momentum to the Sustainable Development Goals (SDGs)? There is a huge knowledge gap between what we know how to do today and what is needed for the future. That knowledge gap is filled by research, including in peer-reviewed journals. I like the way the collaborators for this report have thought about these issues.

Is there information in the report that you think is particularly interesting, unusual or likely to have an effect on the development of the field looking forward?

I am struck by the strength of US publication output in areas related to the theme of People, which, in this analysis, includes filters related to health. It will be interesting to see how this changes over time, particularly relative to rapid research growth in China and other areas. In 15 years the landscape may look different. It is important that policy makers provide a progressive environment that fosters intellectual freedom to encourage growth.

What do you consider to be the greatest opportunities and challenges in sustainability research?

The approach that we have taken at the Harvard Global Health Institute is to ask ourselves, "What are the biggest, most pressing problems that are threatening human progress?" There are certain things we cannot control – acts of terrorism, for example – but where global health is concerned we have identified three primary issues:

- *Climate Change: When many people think about climate change they think about energy policy (Planet); we also consider its impact on global health (People). How do we mitigate rises in CO_2 levels and the resultant effects on health? This requires an understanding of the magnitude and mechanisms that lead to health effects and what we might do to mitigate them.*
- *Aging: It is a new and increasingly urgent issue – how health systems globally will tackle an aging population, one that is growing old quickly and in places that have given little thinking to how to manage the complex problems that will ultimately arise as a result. Many developing countries see the onset of massive urbanization; the cultural structure that got their populations through being older for centuries is no longer available, nor have people ever lived this long.*
- *Establishment of safe and effective health systems: This consideration is broader, but we need health systems that are safe and effective and that engender trust in the population. In deconstructing the Ebola outbreak, a*

> *recent panel involving the health ministries of three countries identified the usual issues – not enough doctors, not enough nurses – but the one consistent issue that arose again and again was trust. Trust comes from a variety of things; being treated with Dignity and respect is part of it, as are consistency and quality of care. Currently there is a big missing link: effectiveness in universal health coverage. If a system isn't trustworthy, the benefits will be limited.*

Most of the issues above fit into the theme of People, but will require an extremely interdisciplinary approach in order to identify solutions. Take, for example, the issue of trust: solving this problem will require the work of not only physicians and life scientists but also management researchers, sociologists, anthropologists, and economists. Healthcare contains a narrow part of the set of capabilities that will be needed. That is why understanding the interdisciplinary nature of sustainability research is important, and this report creates a framework for studying it.

What do you see as the consequences of (recent) large-scale programs on progress in sustainable development generally, and how they are affecting research in individual research centers, the culture of collaboration and the questions being asked?

To take Harvard Global Health Institute as an example, it is a university wide institute, not a school based institute, which means it offers a platform to bring thinkers and ideas together across subject areas. We can facilitate collaborations between the medical school and business school, for example. More broadly, we see great potential in a collaboration strategy across a global set of projects, including work in China, the UK, India and Malaysia. We have a good balance of North-North as well as North-South collaboration and I am glad to see this research dynamic captured as part of the report.

If you are going to work effectively on health systems in Liberia, you don't have to be based there, but you will be more effective if you have Liberian partners. As all of this work gets going, we will not do it simply by sitting in Cambridge, but instead be more effective with global colleagues on the ground in Delhi, Monrovia and Beijing.

Which discoveries in the field of sustainability science have had an impact on the direction of the field as a whole and in what way?

This is really a fourth point that could be included in the rubric mentioned earlier – a hugely important factor is how technology is going to change the delivery of health and healthcare. There is very little scholarship on this yet, and small initiatives, say a mobile healthcare app developed for citizens in Tanzania, have yet to achieve scalability. We need to understand which technological developments can become generalizable knowledge in order to achieve faster and better transformation of healthcare delivery.

There has been much discussion about how sustainability research impacts economic development. What are your comments on this?

There has been an ongoing debate regarding the balance of what can be broadly defined as the themes of People and Prosperity: if you just have economic growth, does this lead to the improved health of a population? We have come to believe this is not such a chicken and egg conundrum. Focusing on economic growth is not enough – societies must invest in health. If governments just invest in economic growth – and this is important for policy makers – they will not necessarily have a healthier population. However, if they invest in health, this will likely have a very positive downstream effect on economic growth, as well as improving the lives of the people it serves.

INTERVIEW

Ian McDougall

Executive Vice President and General Counsel, LexisNexis L&P

What are your general impressions of the report?

This is an excellent starting point for assessing the research landscape relating to the UN Sustainable Development Goals. The internal consistencies, especially in the theme Justice, are reassuring and there is a good level of detail, which will allow subsequent reports to fully explore the finer details.

Does the report highlight any issues you think will be important to consider as the field develops?

The concepts of 'justice' and 'rule of law' are not necessarily the same. Justice is seen as a standard of law, very often as it pertains to a particular country, while "Rule of Law" is a set of universally applicable principles that relate to equality, accessibility, independence and transparency.

I think we need to move away from a focus on justice and start considering the broader benefits that can be realised when the Rule of Law is established.

In many of the measures, such as growth rate or citation impact, research relating to the theme *Justice* did not perform as well as the other themes. Why is that?

Funding is always a problem. I think this can, at least in part, be traced back to a lack of awareness about how important the Rule of Law is to sustainable development. Without this underlying stability, investment in other areas is difficult. Can you have sustainable economic growth without the Rule of Law?

This is a very interesting question but one that has been underserved by research. When we started to investigate this at LexisNexis, we soon realised we would need to conduct some of our own studies. The preliminary results of our research, which is still underway, suggest a strong correlation between Rule of Law and sustainable economic development.

It was no surprise the justice theme had low levels of interdisciplinary research. Much of my work on the concept of Rule of Law is to help people, including within the legal community, to understand the multitude of connections with other areas, such as prosperity, development or economics. This is key and I hope to see the research become more interdisciplinary in the future.

Do you think the findings of this report will help to clarify the importance of knowledge in achieving the Sustainable Development Goals?

Knowledge is essential to making informed decisions if we are to achieve sustainable development. I think, however, we need something more than knowledge; we need understanding. For the Rule of Law to flourish, we need to speak in the language of business and prosperity. Then it starts to become real to people, it starts to become less abstract and more connected to the real world.

1.4 Research focus

Each country has its own strengths and focuses in research, determined by its researcher base and the country's strategies and priorities in social and economic development. In this section, we investigate the differences in research focus in sustainability science of the top five most prolific countries in this research field: the USA, the UK, China, Germany and Australia.

The indicator we use to measure research focus is the relative activity index. A number higher than 1 implies that the country has a higher share of publications in that theme compared to the world average. A number lower than 1 implies a level of research activity that is below the world average.

Spie charts are used in Figure 1.6 to present the relative activity indices (RAI) of the top five countries. The length of the pie slices in the spie chart denotes RAI. The sizes of the pie slices denote the number of publications of the country in each theme, and the color indicates the FWCI of the publications.

The USA shows clear focus on *People*, with a high RAI and the largest proportion of its publications in this theme. This is likely to be related to the USA's research strength in medicine-related subject areas, which contributes to the topics related to improving people's health in this theme. In *Planet* and *Justice*, the USA's level of research activities is close to the world average of 1 and in the other three themes it is far below 1. Across the six themes, the USA's publications have the highest FWCI in *Planet*.

The UK has a balanced distribution of research activities across the six themes: its RAI is close to 1 in all themes except *Prosperity*. The UK has the largest number of publications in *Planet* (15,478 in the period 2009-2013) and *People* (10,336). Similar to the USA, the UK also has the highest FWCI in *Planet*.

Planet dominates China's research in sustainability science. It has a RAI higher than the world average and the largest absolute number of publications among the six themes. China has the highest level of research activity in *Prosperity* (76% higher than the world average). However, the FWCI of China's publications in this theme is low – 12% below the world average. In contrast to the USA and the UK, China has the highest FWCI in *People*. There is a very low level of research activity in *Dignity*, *Justice* and *Partnership* in China.

Similar to China, *Planet* also dominates the landscape of Germany's research in sustainability science. There is a small number of publications and a low level of research activity in the other five themes for Germany.

Germany and China's focus on *Planet* is likely to be related to the countries' research base: the strengths of the countries' research lie in subject areas in the domain of natural sciences. *Planet* is a theme that mostly covers publications from these subjects (see Appendix E for the subject distribution of publications in each theme).

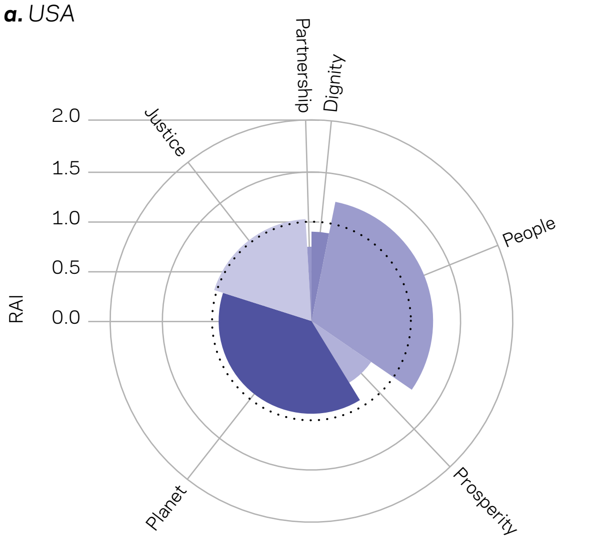
Australia also has the largest number of publications and a RAI higher than 1 in *Planet*. *Partnership* makes Australia stand out from the other four countries: it has the highest RAI (62% higher than the world average) and a high FWCI (1.92).

What is relative activity index ?

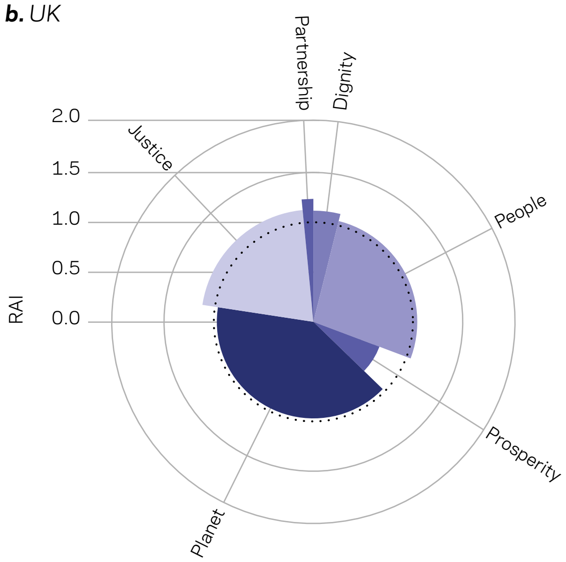
Relative activity index is defined as a country's share of publications in a subject field relative to the global share of publications in the same subject field.

To illustrate this calculation, the USA publishes 3,533 papers in Dignity in the period of 2009-2013, and 105,507 papers in sustainability science overall. The world published 12,432 papers in the theme Dignity in the period 2009-2013, and 334,019 papers in sustainability science overall. Therefore, the relative activity index for the USA in Dignity is (3533/105507)/(12432/334019)=0.90.

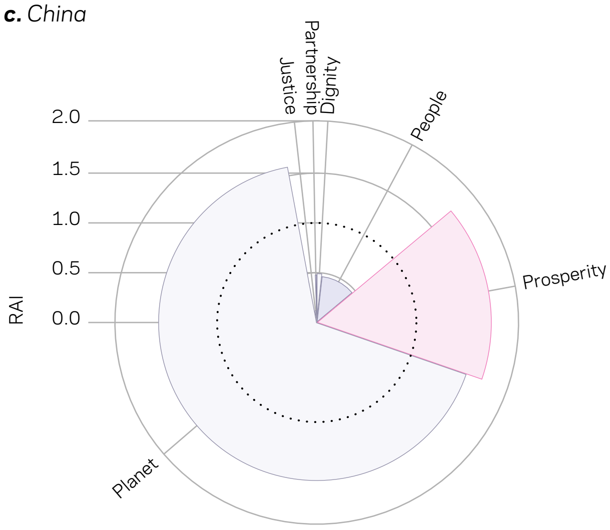
a. *USA*



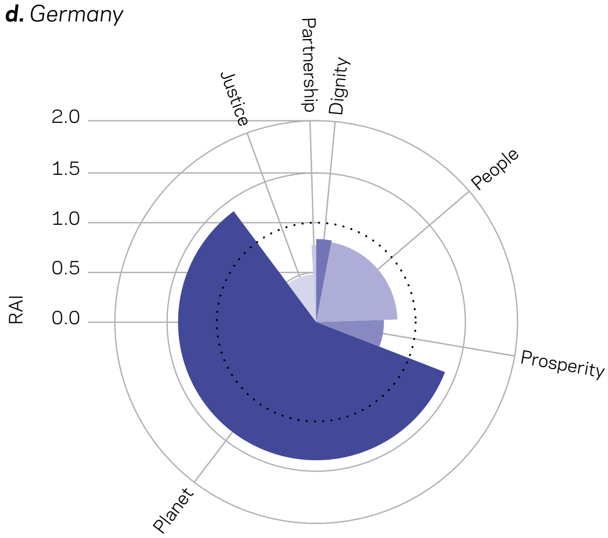
b. *UK*



c. *China*



d. *Germany*



e. *Australia*

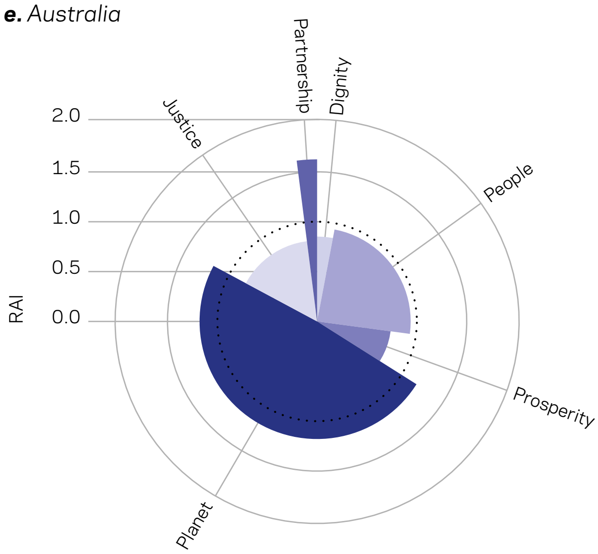
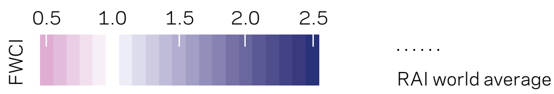


Figure 1.6 *— Research focus; per country for the top five most prolific countries in sustainability science; per theme for sustainability science; for the period 2009-2013. The size of the pie slices denotes the number of publications, the length denotes RAI and the color indicates FWCI. The black dotted line indicates the world average of 1.*



INTERVIEW

Yishan Wu

Vice President, Chinese Academy of Science and Technology for Development. An expert on bibliometrics, he has been involved in bibliometrics studies since 1992 and has published more than 60 papers in this field.

In your opinion, why is studying a research field using bibliometrics important for research that supports sustainable development?

All databases, including Scopus, are based on journals, and the creation of journals is usually based on disciplines. The management of all foundations, including the US National Science Foundation and the National Natural Science Foundation of China (NSFC), is also based on disciplines. However, research on a comprehensive topic such as sustainability science requires integrated information. In other words, the existing discipline classification, funding structure and journals cannot meet the needs of research that supports sustainable development. It is therefore important to conduct studies, as in this report, to investigate the status of sustainability science in an integrated way.

Today, human beings face many complicated, cross-disciplinary issues, such as AIDS prevention and population control, but our knowledge is divided into various disciplines, and reflected in discipline-specific journals. To facilitate research that supports sustainable development, there is a need to have journals specifically for the field. Through the analysis in this report, we can identify which existing journals are more relevant for this field. By paying special attention to sustainability science journals, research achievements in connection with this topic can be reflected in a centralized way.

Bibliometric studies will also help researchers acquire a more comprehensive understanding of the status of research on sustainable development and identify their peers who are conducting similar research.

How is the use of bibliometrics to study sustainability science relevant to policy?

The analysis of the quantity of research output is very relevant to policymaking. Take the UN for example, all aspects of its work have a priority, and with this kind of analysis we can assess whether the quantity of our existing literature matches its priority fields. If the quantity of literature for the priority fields is small, the UN can then make adjustments.

In addition, analysis can also be conducted on citations and funding. Take HIV/AIDS for example: analysis can be conducted to show how many projects the WHO or the NIH in the US has initiated and invested in. Citations to the related literature can indicate to some extent the return on their investment.

Such bibliometric analysis is very necessary for studying complicated issues. As mentioned earlier, the knowledge we have is divided. The Ministry of Science and Technology of China has put forward 16 major national projects in the national medium and long term plan towards 2020, but where is the literature *corresponding to those projects? Since the existing disciplinary division does not correspond to issues or fields of our concern, it is a huge challenge to find all the relevant literature, research institutes and researchers. Bibliometric study will contribute significantly in this respect.*

What value do you think this report will bring?

The greatest value is providing data-based evidence; anything we do needs the support of facts and data, including literature. Therefore, it is an extraordinary attempt to use bibliometric methodology to analyze a major topic such as sustainability science. I say it is extraordinary because I know it is hard, but it is also worthwhile and should continue.

On the other hand, consideration shall also be given to the spillover effect of this project, extending from literature management to knowledge and funding management. The question is whether, or to what extent, this management should switch from something that is based on disciplines to something that focuses on the topics of concern, such as sustainable development.

In your opinion, what will be the biggest challenge for sustainability science in the future?

Our existing knowledge management system, i.e. journal classification, runs counter to our needs to really solve the problems. How can a scientist rapidly build his or her own credit? The traditional experience is to specialize – it is not enough to say you are a physicist, it's better to be a condensed-matter physicist or something like that. And it's even better to be specialized in superconductivity, and even better in high-temperature superconductivity. However, in reality, we are faced with the need to be integrated.

Big problems also exist in the current management systems. For example, NFSC has a number of departments, including the Department of Mathematical and Physical Sciences, the Department of Life Sciences, the Department of Information Sciences, and so on. When applying for grants, every researcher has to figure out to which department his or her proposal should be submitted. But proposals dealing with sustainability science are closely connected with every department, and just could not be pigeonholed into any of those departments properly.

We all say interdisciplinary research is important, but the challenge is how to implement it. In China for example, sustainable development involves many government agencies, including the National Health and Family Planning Commission, the Ministry of Environmental Protection, the Ministry of Science and Technology and many others. However, the funding sources for sustainability science are rather fragmented. Is it possible for the National Development and Reform Commission of China, for example, to set up a dedicated department for sustainable development? Only with system support and dedicated responsible people can things be done well.

Chapter 2 Research Collaboration

In this chapter, we investigate collaboration in sustainability science. Various aspects of collaboration are explored: collaboration across countries, North-South collaboration, collaboration between authors from different subject areas and collaboration across sectors (academic, medical, corporate and government).

2.1 Key findings

SHARE OF INTERNATIONAL COLLABORATION

71.6 %

Switzerland leads the top 15 most prolific countries in terms of share of international collaboration. In 2013, 71.6% of its publications in sustainability science were co-authored with international colleagues.

COLLABORATIVE PARTNERS

24.3 %

In the period 2009-2013, 24.3% of the collaborative publications between the Netherlands and Kenya belong to sustainability science. This share is the highest among all partners with more than 100 collaborative publications.

Strong connections between research intensive countries and African countries

In sustainability science, there are strong connections between Africa and research intensive countries such as the USA, Canada and Western European countries.

Collaboration across sectors focuses on health

In sustainability science, collaborations between academia and the medical sector, and between academia and the corporate sector, are most intensive in health-related subject areas.

2.2 International collaboration

Collaboration across countries has become more and more frequent in research.[48] Convenient and cheaper modes of transportation and the development of internet-based communications have made cross-border research collaboration easier and more efficient. More importantly, many of the issues the world is facing today are global in nature and require global responses.[49] This is particularly true for sustainability science: one can hardly think of any questions in this research field that do not require collaborative efforts from multiple countries, whether they are addressing poverty, gender inequality, HIV, climate change or social justice. Sustainability science connects many areas of science and connects east with west, north with south – it strongly links nations or regions that are emerging scientifically in terms of research with nations that are more mature. Understanding the collaboration networks within sustainability science reveals the direction of research and guides investments and attention toward specifically where important work is happening, progress is made and needs are highest.

Sharing of authorship on a published, peer-reviewed paper reflects a tangible engagement, so we use co-authorship as a proxy for collaboration.[50] Figure 2.1 presents the share of internationally collaborative publications out of their total research output in sustainability science for the top 15 most prolific countries. European countries, including Switzerland, Sweden, the Netherlands, France, Germany and Spain, have the highest shares. Switzerland leads, with 64.3% of its research output in sustainability science involving international collaborators in 2009, increasing to 71.6% in 2013. As a benchmark, the share of internationally collaborative publications out of Switzerland's total research output increased from 60.3% in 2009 to 63.9% in 2013.

> *"I would say that our business is a very globalized family business. We are very small in our numbers in the scientific community, therefore we need to find out collaborators not only within our country, but also in other countries; otherwise we would not be able to develop our work."*
>
> *— Kazuhiko Takeuchi, United Nations University and University of Tokyo*

Brazil, the USA, China and India have the lowest share of international collaboration in sustainability science. These four countries all have a large number of publications resulted from collaborative efforts across institutions within the country or faculties within institutions. Previous research has shown that if we view the states in the USA as independent entities, the level of collaboration across states in the USA is similar to that of collaboration across countries in Europe.[51]

The FWCI of these internationally collaborative publications is high. For Switzerland, it is 2.77 in 2013, while the corresponding FWCI of Switzerland's publications in sustainability science is 2.35 (see Figure 1.5). Even for India, which has an FWCI in sustainability science below the world average of 1, the FWCI of its internationally collaborative publications in this research field is much higher – close to 1.8. This is a pattern we often observe: international collaboration is associated with higher FWCI.[52] International collaborative publications are likely to be exposed to wider research communities and therefore are more likely to be accessed and cited.

48 Leydesdorff, L. and Wagner, C.S. 'International collaboration in science and the formation of a core group'. Informetrics 2 (2008): 317–325.

49 Rees, M. 'International collaboration is part of science's DNA'. Nature 456 (2008): 31.

50 Adams, J. 'Collaborations: The rise of research networks'. Nature 490 (2012): 335-336.

51 See Elsevier's report in collaboration with Science Europe at *http://www.scienceeurope.org/uploads/PublicDocumentsAndSpeeches/SE_and_Elsevier_Report_Final.pdf.*

52 See the report "International Comparative Performance of the UK Research Base – 2013" conducted by Elsevier for the UK Department of Business, Innovation and Skills, available at *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263729/bis-13-1297-international-comparative-performance-of-the-UK-research-base-2013.pdf.*

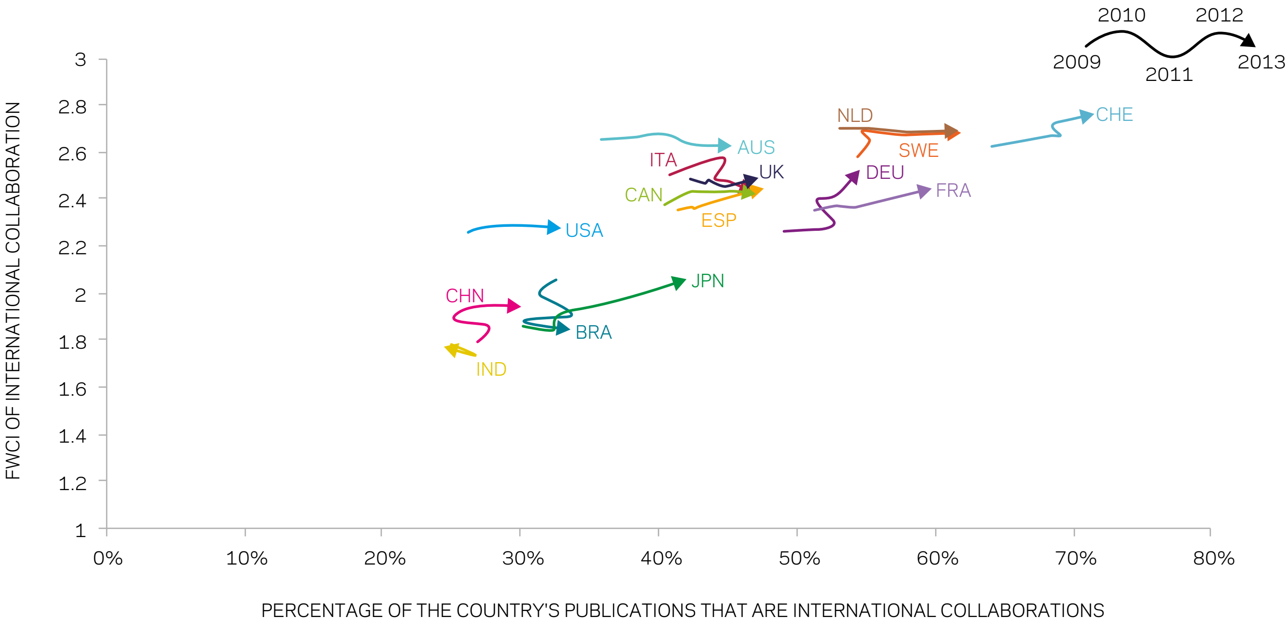


***Figure 2.1** — Share of internationally collaborative publications out of the country's total publications and FWCI of international collaboration; per country for the top 15 most prolific countries in sustainability science; for sustainability science; per year for the period 2009-2013.*

The proportion of international collaboration also differs by theme (Figure 2.2). The USA, the UK, Germany and Australia all have the highest share of international collaboration in *Planet*. The publications in *Planet* mainly consist of publications in agricultural & biological sciences, earth & planetary sciences and environmental sciences (Appendix E). All three subject areas have a higher percentage of international collaboration worldwide (25.1%, 27.4%, 21.3%, respectively) than the world average for all subjects (17.4%). This contributes to the high share of international collaboration among *Planet* publications.

Partnership has the second highest share of international collaboration for the USA, the UK and Germany, followed by *Dignity* and *People*. Australia has the second highest share of international collaboration in *People*. *Justice* has the lowest level of international collaboration. The high share of international collaboration in *Partnership* is no surprise, since the theme focuses on collaboration in research. *Justice* consists mostly of publications in social sciences and humanities, both of which have a low level of international collaboration (11.1% and 7.4% worldwide, respectively).

China is the only country that shows a very different pattern among the top five countries. It has the lowest share of international collaboration in its two largest themes – *Planet* and *Prosperity* – and the highest share in *Dignity*, *People*, and *Justice*, all of which contribute to only a small portion of the country's publications in sustainability science (Figure 1.6).[53] One plausible explanation is that for emerging countries there is a higher need for researchers in small subject areas to go beyond their country's border in order to find co-authors that share similar interests and have complementary resources and skills.

To give an overview of the collaboration across countries in sustainability science, in Figure 2.8 we plot the collaboration network at the country level. The countries that intensively collaborate with each other, as measured by Salton's index, are plotted close to each other. Countries in the center of the chart serve as the core of the collaboration network by connecting many countries to each other.

Countries that are geographically close to each other are usually clustered in the network. On the top part of the chart we see a cluster of Middle East countries and a cluster of South Asian, Southeast Asian and Oceanian countries. North American, African, and European countries are in the middle. At the bottom of the chart, we see many East European countries. This implies that even though collaboration is increasing worldwide, it is still most likely to occur among neighboring countries that are more likely to share similar research system, culture and language.

The two most intensively connected clusters are the Europe plus the USA and Canada cluster and the Africa cluster.[54] These two clusters are closely linked to each other mostly through East African countries, South

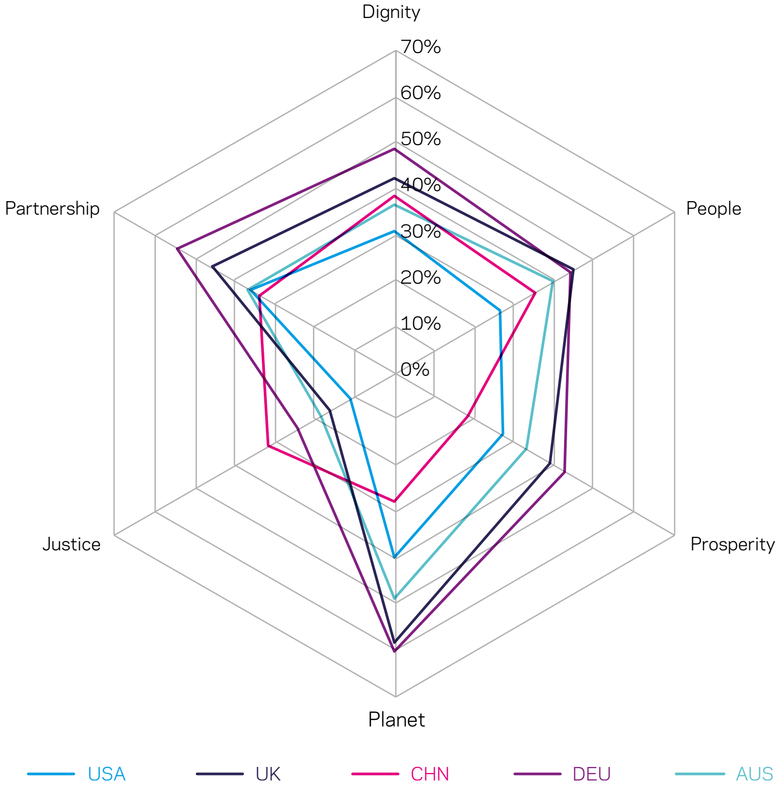


Figure 2.2 *— Share of internationally collaborative publications out of the country's total publications; per country for the top five most prolific countries in sustainability science; per theme for sustainability science; for the period 2009-2013.*

Africa, the USA, Canada, the UK and France. This is a characteristic that applies especially to sustainability science. If we were to plot the same chart using data from all Scopus publications, we would see that African countries are mostly at the margin of the network and their connections with the core of the chart (North American and European countries) are much less intensive.[55]

This is of course related to the nature of sustainability science, which requires global collaboration, and Africa is a continent that plays a key role for achieving the SDGs, in particular in areas such as poverty, sustainable agriculture, health and education. The role of East African countries in international collaboration is also reflected in previous studies. For example, the report 'A decade of development in Sub-Sahara African science, technology, engineering & mathematics research' conducted by Elsevier in collaboration with the World Bank[56] shows that over 70% of the peer-reviewed research output from East African countries involves international collaboration.

What is Salton's index?

Salton's index, also known as Salton's cosine or Salton's measure for a country pair, is calculated by dividing the number of co-authored articles by the geometric mean (square root of the product) of the total article outputs of the two partners, hence it is a size-independent indicator of collaboration strength.

As a cosine measure, the values of Salton's index vary between 0 (where there are no co-authored articles between a given country pairing) and 1 (where all articles from both countries represent co-authorship between them).

53 This finding is consistent with Lau, G., and Pan, L. 'Researcher mobility in different stages of national research development'. Academic Executive Brief 4(2) (2014): 10-14. They found that researcher mobility is usually higher for smaller subject areas for China.

54 This finding is in line with Bettencourta, L.,and Kaurc, J. 'Evolution and structure of sustainability science'. PNAS 108 (49) (2011): 19540-19545. The authors stated that "the field is widely distributed internationally and has a strong presence not only in nations with traditional strength in science—e.g., the United States, Western Europe, and Japan—but also elsewhere."

55 For an example of such a chart, see page 65 of Elsevier's report for the UK Department of Business, Innovation and Skills, available at *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263729/bis-13-1297-international-comparative-performance-of-the-UK-research-base-2013.pdf*

56 See *http://www.elsevier.com/research-intelligence/research-initiatives/world-bank-2014*

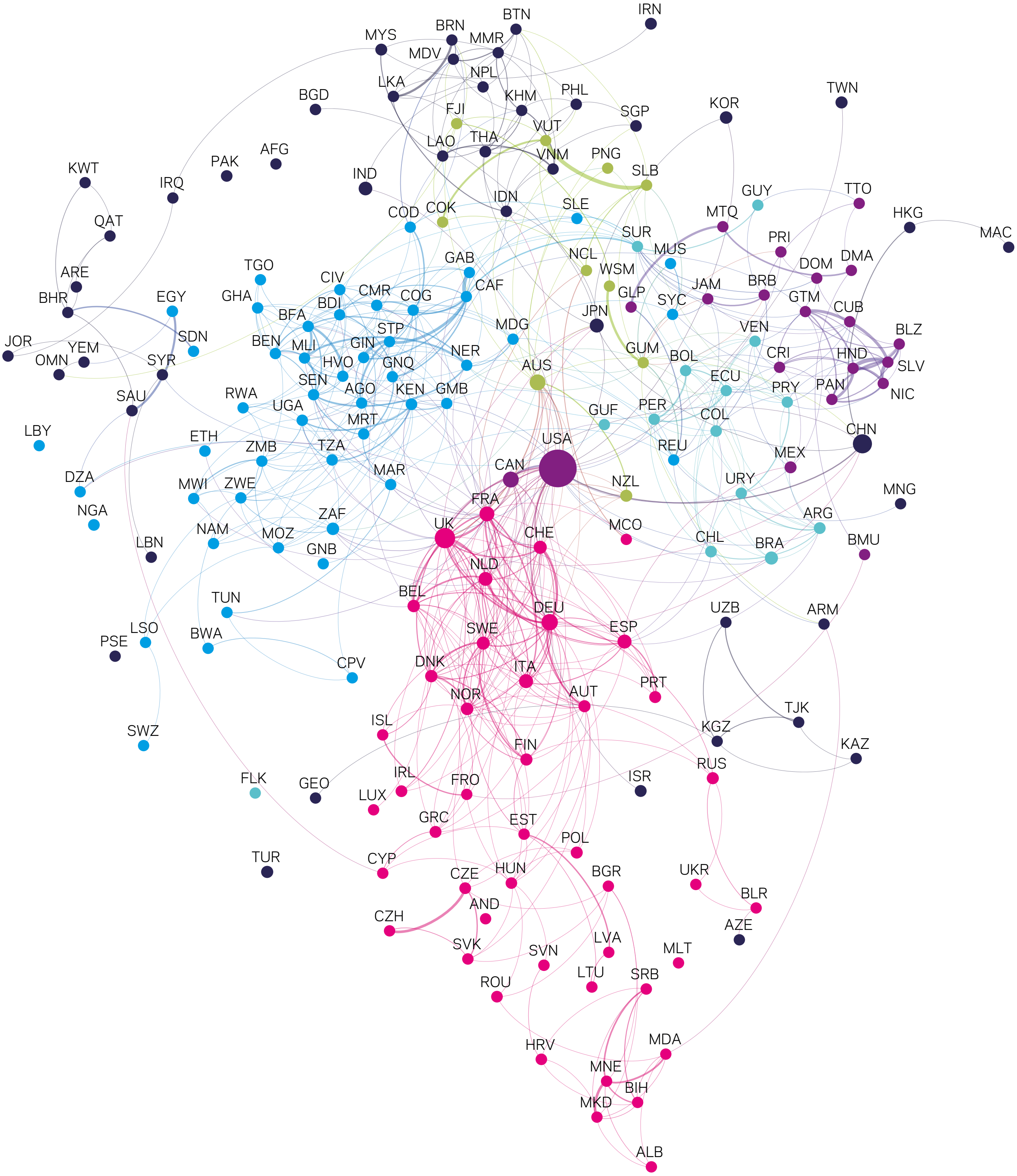


Figure 2.3 *— Network map of countries; for the world; for sustainability science; for the period 2009-2013. The size of the nodes denotes the number of the publications of the country. The color of the nodes and edges denotes the continent (dark blue: Asia, blue: Africa, pink: Europe, purple: North America, green blue: South America, green: Oceania). The length of the edges denotes Salton's index. Nodes with less than 10 connections and edges with a Salton's index less than 0.026 are not shown. Force Atlas 2 algorithm is used for the layout.*

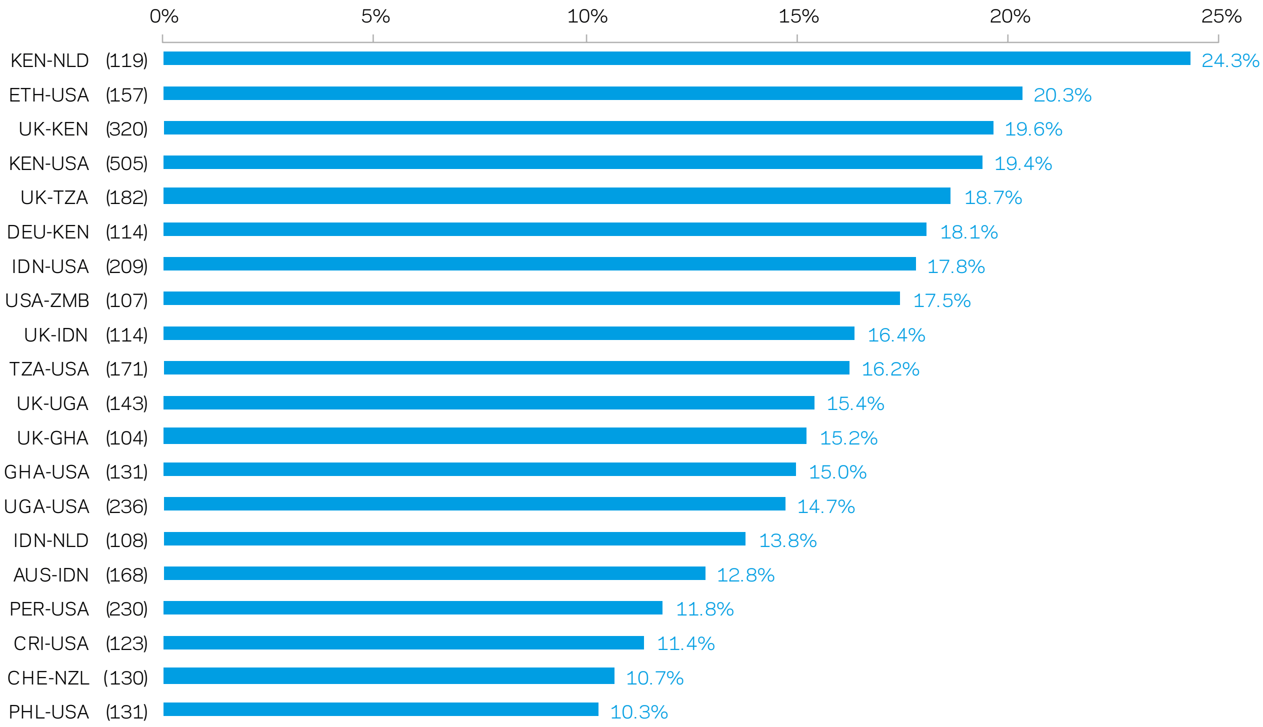


Figure 2.4 *— Top 20 pairs of countries with the highest share of collaborative publications in sustainability science out of all collaborative publications (the two countries need to have at least 100 collaborative publications in sustainability science); for the world; for sustainability science; for the period 2009-2013. The numbers in the bracket are the number of collaborative publications in sustainability science.*

The close linkage between the research intensive North American and European countries and African countries in sustainability science is further confirmed in Figure 2.4, which presents the pairs of countries with the highest share of collaborative publications in sustainability science relative to all collaborative publications between the two countries.[57] Most of the pairs are formed by one country from Africa and one country from the research intensive North American and European countries. The partnership between Kenya and the Netherlands leads the top 20 collaborating partners, with 24.3% of their collaborative publications belonging to sustainability science. Indonesia also appears in many of the partner pairs (with the USA, the UK, the Netherlands and Australia).

57 Collaboration involving a large number of countries is relatively rare in sustainability science. For example, only 1,348 out of 146,885 2009-2013 publications in *Planet* involve authors from more than five countries.

2.3 North-South collaboration

Many international programs and initiatives have been or are being set up to strengthen international collaboration and in particular the partnership between developed and developing countries (also called North-South collaboration). Examples are the Sustainable Development Solutions Network, which stimulates scientists and technology experts outside of government to support the development of long-term analyses, demonstration programs and development pathways,[58] and the United Nations Decade of Education for Sustainable Development, which aims to integrate the principles, values and practices of sustainable development into all aspects of education and learning.[59]

Collaboration is key to addressing the issues sustainability science is trying to solve, and to achieving the SDGs. One of the targets of the SDGs is to enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms. Successful collaboration depends on all parties having a certain level of scientific and technological capacity. That is a primary reason why scientific capacity must be built in developing countries, and international collaboration gives new life to the impetus to support scientific capacity in developing countries.[60]

To investigate to what extent developed and developing countries are collaborating with each other, we grouped the countries according to the World Bank definition: developed countries are the high-income countries and developing countries include both middle-income and low-income countries.

The majority of publications in sustainability science are produced by high-income countries (254,629, 76% of all publications in sustainability science in the period 2009-2013). Low-income countries only produced 2% of the publications in this field. This is an indication that there is still a need to strengthen the research infrastructure of developing countries, in particular low-income countries.

Figure 2.5 presents the number of publications within and across income classes. Income classes of the countries are denoted by the circle's segments. The number of the (collaborative) publications is indicated by the width of the connecting lines. If the origin and destination of the line are both within one segment, the line represents the publications produced within the income class. The majority of North-South collaborations occur between high-income and upper-middle-income countries. There are in total 19,250 collaborative publications between these two income classes,[61] contributing to 5.8% of publications in sustainability science for the period 2009-2013. However, on average these 19,250 publications only contribute to 7.6% of high-income countries' publications in this field. Collaborations between high- and lower-middle-income countries and between high- and low-income countries

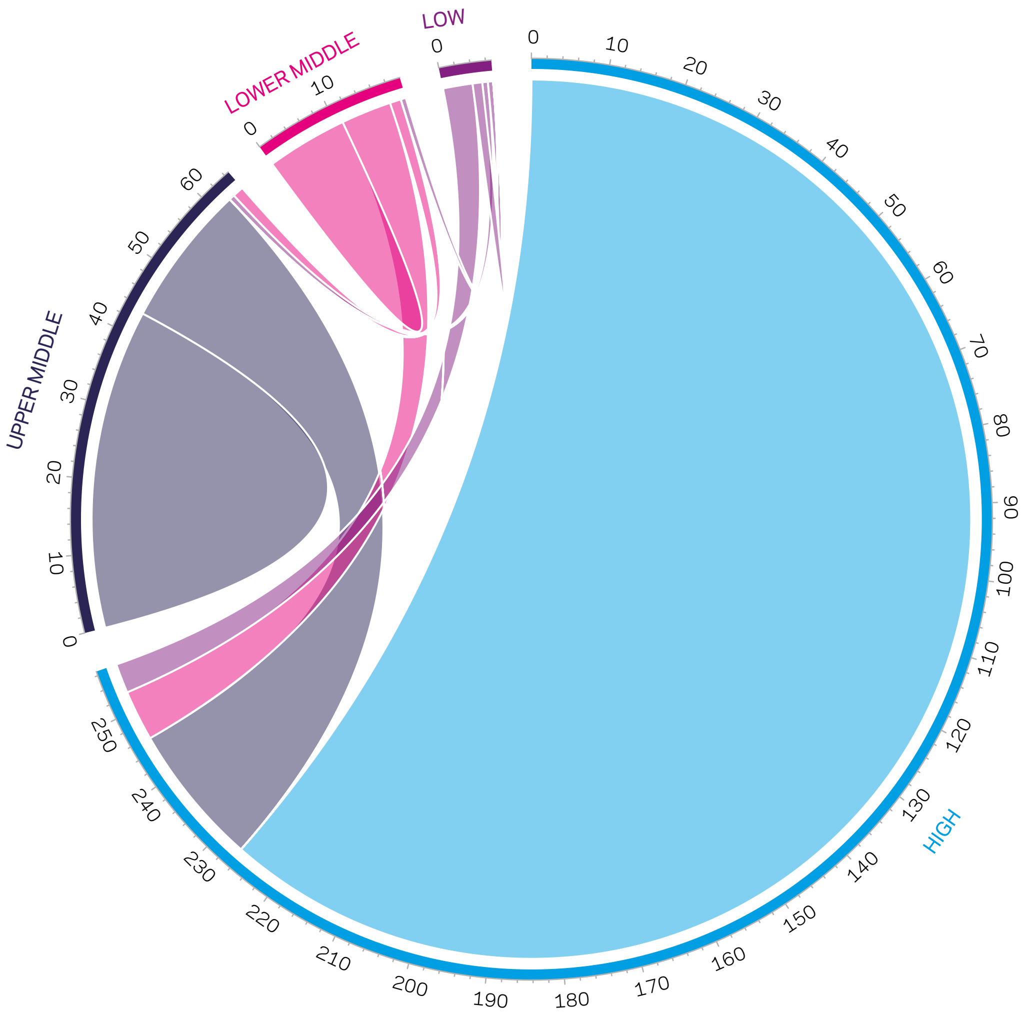
Developed and developing countries

According to the United Nations Statistics Division, there is no established convention for the designation of "developed" and "developing" countries or areas in the United Nations system.

We therefore adopted the World Bank's definition of "developed" and "developing" countries. The World Bank classifies countries into four income classes according to their Gross National Income (GNI) per capita. For the current 2015 fiscal year, low-income economies are defined as those with a GNI per capita, calculated using the World Bank Atlas method, of $1,045 or less in 2013; middle-income economies are those with a GNI per capita of more than $1,045 but less than $12,746; high-income economies are those with a GNI per capita of $12,746 or more. Lower-middle-income and upper-middle-income economies are separated at a GNI per capita of $4,125.

Developed countries include the high-income countries according to this classification and middle- and low-income countries are classified as developing countries. For a complete list of countries in each income classes, see http://data.worldbank.org/about/country-and-lending-groups and Appendix B.

As noted by the World Bank, the term country, used interchangeably with economy, does not imply political independence but refers to any territory for which authorities report separate social or economic statistics. The term developing, used to denote low- and middle-income countries, does not imply that all economies in the group are experiencing similar levels of development or that other economies have reached a preferred or final stage of development.



LOW-INCOME COUNTRIES

Publications: 5,597
2% of all publications in sustainability science

Collaborative publications

With high-income countries:	3,992 (71.3%)
With upper-middle-income countries:	752 (13.4%)
With lower-middle-income countries:	707 (12.6%)

LOWER-MIDDLE-INCOME COUNTRIES

Publications: 18,360
6% of all publications in sustainability science

Collaborative publications

With high-income countries:	6,833 (37.2%)
With upper-middle-income countries:	1,498 (8.2%)
With low-income countries:	707 (3.9%)

UPPER-MIDDLE-INCOME COUNTRIES

Publications: 63,069
19% of all publications in sustainability science

Collaborative publications

With high-income countries:	19,250 (30.5%)
With lower-middle-income countries:	1,498 (2.4%)
With low-income countries:	752 (1.2%)

HIGH-INCOME COUNTRIES

Publications: 254,629
76% of all publications in sustainability science

Collaborative publications

With upper-middle-income countries:	19,250 (7.6%)
With lower-middle-income countries:	6,833 (2.7%)
With low-income countries:	3,992 (1.6%)

***Figure 2.5** — The number of collaborative publications across income classes; for the world; for sustainability science; for the period 2009-2013. The numbers in the bracket are the share of collaborative publications out of all publications of the countries in the income class.*

58 See *http://unsdsn.org/* for more information.

59 See *http://unesdoc.unesco.org/images/0014/001486/148654e.pdf* for more information.

60 Rees, M. 'International collaboration is part of science's DNA'. Nature 456 (2008): 31.

61 A publication is defined as a collaborative publication between two income classes, if there is at least one author from countries in the first income class and also at least one author from countries in the second income class. If a publication has authors from a high-income country, an upper-middle-income country and a low-income country, this publication is counted toward high-upper-middle collaboration, high-low collaboration and upper-middle-low collaboration.

comprise 2.0% and 1.2% of all sustainability science publications. However, these collaborative publications with high-income countries play an essential role for lower-middle- and low-income countries, accounting for 37.2% and 71.3% of all publications of those income classes, respectively.

There are a small number of collaborative publications between different income classes within developing countries. This is probably related to the relatively low research capacity such as social capital, funding opportunities, incentives for career development within low-income countries. This finding is in line with previous studies. For example, due to such issues the Elsevier-World Bank report "A decade of development in Sub-Sahara African science, technology, engineering & mathematics research" found that only a small percentage of Africa's publications resulted from collaboration within Africa.

It is to be expected that high-income countries with a large volume of research output contribute to a large number of collaborative publications between the North and the South. Conversely, low-income countries have a small number of publications, and therefore in absolute terms they do not contribute a large number of collaborative publications. To explore further how important these collaborative publications are to each country, we take a closer look at collaborations between developed and developing countries at the country level.

Figure 2.6 presents the share of North-South collaborative publications out of the country's total publications in sustainability science for the top 10 developed countries with the largest number of collaborative publications with the South. The USA has the largest number of collaborative publications (12,152 in 2009-2013), followed by the UK (4,871) and Germany (2,765). Among the top 10 developed countries, Switzerland has the highest share of North-South collaborative publications out of its total publications in sustainability science (16.1% in 2009 and 19.6% in 2013), followed by France, Japan and the Netherlands. We also see that even though North-South collaboration only contributes to a relatively small percentage of publications for these 10 developed countries, the percentage increased from 2009 to 2013 for all 10 countries. Japan shows the largest increase, from 13.8% in 2009 to 19.2% in 2013.

In general, 10-20% of the publications in sustainability science of the top 10 developed countries are produced in collaboration with developing countries. These collaborative publications however comprise a major part of the publications of developing countries in sustainability science. Figure 2.7 presents the top 10 countries with the largest number of collaborative publications with developed countries for each income class within developing counties. We see that North-South collaborative publications contribute to more than 40% of total publications in sustainability science for six of the top 10 upper-middle-income countries in 2013. For the top 10 lower-middle-income countries, the share is even higher: five of them have a percentage of higher than 50% in 2013. For the top 10 low-income countries, all countries except one (Zimbabwe) have a share higher than 60% in 2013. Collaborating with developed countries therefore plays an essential role in sustainability science for developing countries, in particular for low-income ones.

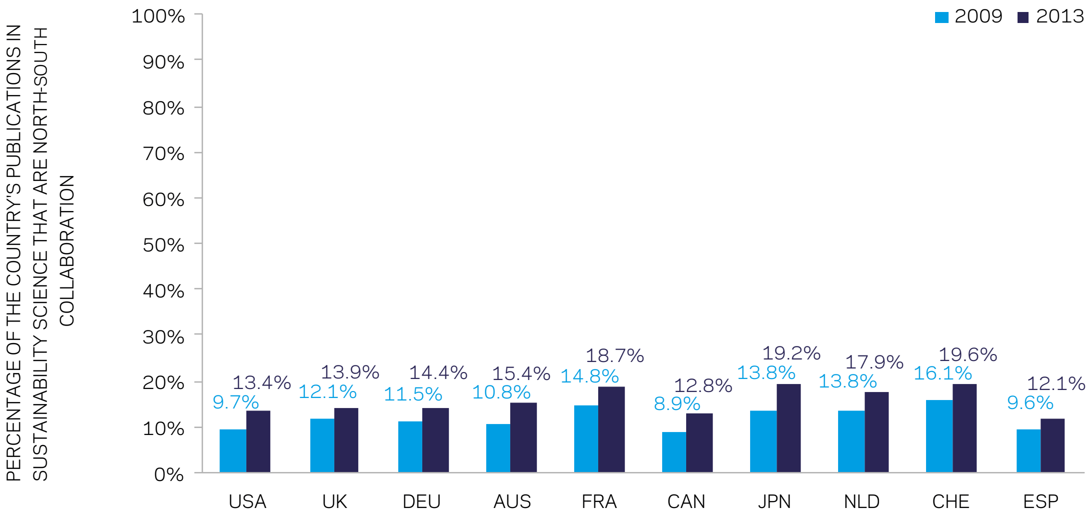


***Figure 2.6** — Share of collaborative publications with developing countries out of the country's total publications in sustainability science; per country for the top 10 developed countries with the largest number of collaborative publications with developing countries; for sustainability science; 2009 and 2013. The countries are ordered by the number of collaborative publications with developing countries in the period 2009-2013.*

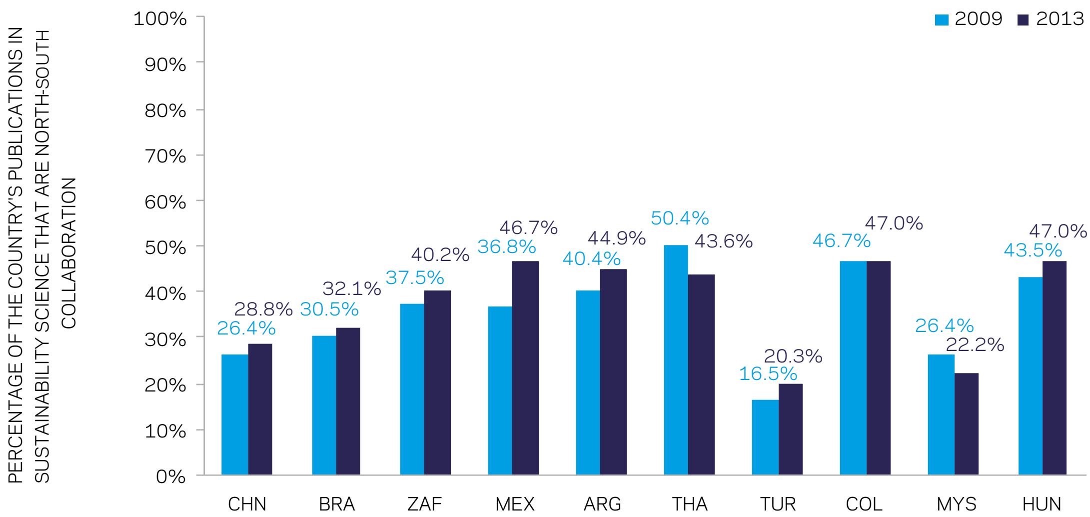
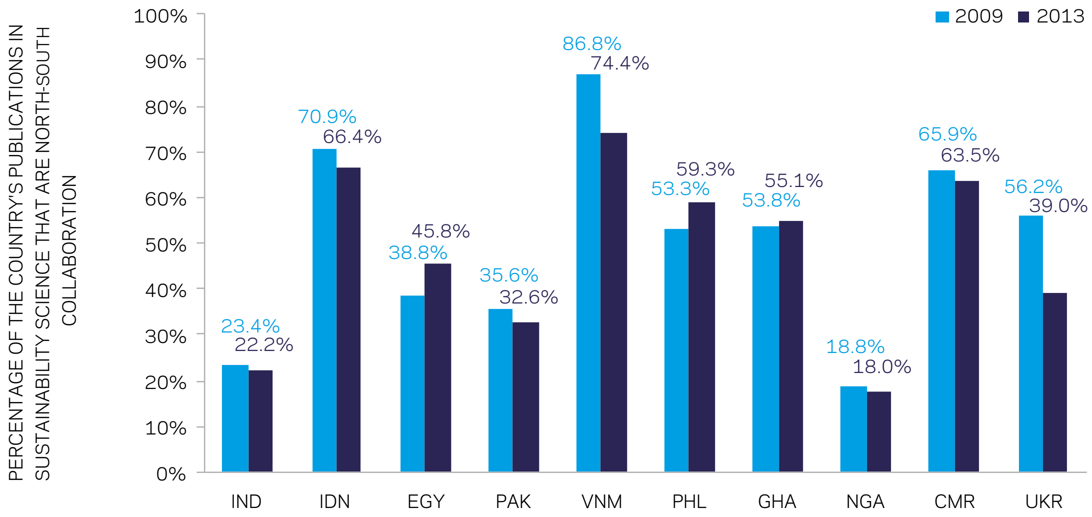
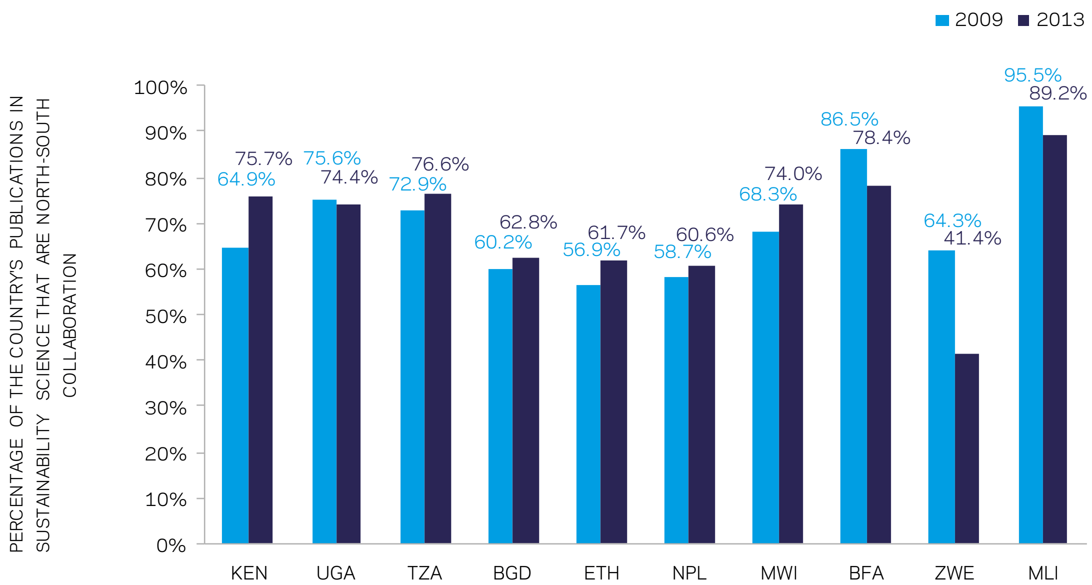


***Figure 2.7** — Share of collaborative publications with developed countries out of the country's total publications in sustainability science; per country for the top 10 developing countries with the largest number of collaborative publications with developed countries; for sustainability science; 2009 and 2013. The countries are ordered by the number of collaborative publications with developed countries in the period 2009-2013.*
a. Top 10 upper-middle-income countries with the largest number of collaborative publications with developed countries



b. Top 10 lower-middle-income countries with the largest number of collaborative publications with developed countries



c. Top 10 low-income countries with the largest number of collaborative publications with developed countries

INTERVIEW

Joshua Tewksbury

Professor, College of the Environment, University of Washington

What did you think of the report?

This is a really important piece of work – looking at patterns that will define the future. One of the things that I see is Elsevier moving from a content provider to a thought leadership position across a defined subject area for the greater good of society. The battle to correctly define sustainability science is almost unwinnable, but this structure makes considerable headway. This research is attempting to assess major processes at a global level. One problem is that many audiences are not yet up to speed. Academia is involved, but there are multiple levels determining how the landscape of information is changing. Labels like sustainability start to create incentive structures for science. The needs of society can potentially drive academic incentives.

Is there information in this report that you think is particularly interesting, unusual or likely to have an effect on the development of the field looking forward?

What is positive about the report is that it is presented as information; this is what is – the current state of affairs, not necessarily what it should be. An objective is to understand what the sustainability world looks like and how it is changing; this foundation can form an important part of the knowledge ecosystem. The genesis of this information can have more impact depending upon how it is tracked. There is, or should be, a link between what scientists think is important and what society thinks is important. This report can help to establish that. It is important to examine how we collaborate across institutions and, more importantly, across disciplines and sectors over time.

We don't have a really good way of tracking or rewarding the authors who are having the most influence on sustainable development. Reports and news media also figure in; there is a complex ecosystem between knowledge creation and knowledge use. There is increasing pressure on publications to arrive at the right places and at the right time. The lack of certainty about when certain things will be published influences private and public sectors in terms of how they get their information. There is a need to connect the scientific literature with public campaign style impact. Further, we need more research to determine how much of the grey literature (for example, conservation reports) draws on peer review.

Are there any aspects of this report that you think should be further explored in relation to Europe/APAC/Africa/America or on a global level?

Capturing the way North-South collaboration changes over time is very important. The colonial nature of conservation still persists. Geopolitical aspects of science are embedded in this latest report, and some of the new realities are worth exploring – Brazil to Africa or China to Africa – this is a touchstone for future work about how the scientific culture shifts or responds to geopolitical reality. We could potentially examine the impact of the investment China is putting into East Africa. Further, capturing growth in China is incredibly important. We need to understand how emerging economies are influencing the literature.

How do you view the value of continued sustainability research or in one of the six Essential Elements (themes) today?

Sustainability research is an interdisciplinary connector. This report can potentially provide context for a community that is strong but inwardly focused: take ecology, for example. Understanding how ecology and other fields fit into sustainability science and how this changes over time is important. We'd like to see which fields play well with others and how this influences society as a result.

There has been much discussion about how sustainability research impacts economic development. What are your comments on this?

The private sector is really interesting to explore – there are very few private sector actors in the sustainability science literature; however, many play a powerful role – Bloomberg, the World Resources Company (WRC) and the Stockholm Environment Institute, to name a few. Private sector consultancy is a one-stop shop for many governments, whether it's designing bus system in Mexico, or cities development in Asia. These actors have tremendous influence that is not necessarily captured in the scientific literature.

What do you consider the most important factors affecting how the sustainability research field has developed in your country/ region?

I've been wrestling with this a lot; looking at the relationship between conservation and development. For example, Goldman Sachs is now looking at natural assets; not just manufactured goods. A company's value now might be dependent upon the water rights they can secure; there is a growing recognition of scarcity of environmental resources. This scarcity creates a crucible for sustainability research – the collection of content that comes from very different fields that must now be melded together to form solutions. Conservation is now seen by many organizations as too narrow, we are increasingly talking about sustainability in broader terms. The big questions we face now are all interdisciplinary, they all involve human systems interacting with natural systems or non-human systems. For example, while we absolutely do need to increase agricultural productivity in many regions of Africa, we want to avoid some of the extreme negative environmental consequences that came with the green revolution. We need a creative way of preserving ecosystem integrity while increasing agricultural productivity. The science of sustainability acknowledges our lack of capacity to predict the future but at the same times seeks to shape it.

[The participants gratefully acknowledge discussions with Dr. Lisa Graumlich, Dean of the College of the Environment, University of Washington.]

2.4 Collaboration across subject areas

As a research field that spans many subject areas, sustainability science often involves researchers from different subject areas collaborating together. Between which research areas do researchers collaborate most frequently?

Figure 2.3 is a network map that presents to what extent researchers from different subject areas[62] collaborate with each other. We see that the network has four clusters.[63] The pink cluster consists of subject areas that are closely related to the theme *Planet*. The purple cluster mostly consists of subject areas in chemistry and engineering, which are likely to be linked to the SDGs on energy covered mostly by the theme *Prosperity.* The blue cluster has a large concentration of biology and medical subject areas that are related to the SDGs on health. Health is mostly covered by the theme *People* but it is also a component of other themes such as *Planet*. Biology is also important for research on *Dignity*, especially on food security. We also see a small cluster (green) of subject areas including law, psychology, education and development. These subject areas are likely to be related to the themes *Dignity* (poverty and inequality), *People* (education and gender) and *Justice*. *Partnership* may cover any of the subject areas.

What is interesting from the network is that the subject areas related to agricultural sciences serve as the hubs linking the two largest clusters (pink and blue). Agricultural sciences is closely connected to research on environment (covered in *Planet* in the pink cluster in the chart) and food security (covered in *Dignity* in the blue cluster in the chart).

Collaboration across subject areas

We first assigned each author a subject area in which the author publishes the majority of his/her publications. We then assigned each publication to subject areas based on the main subject areas of its authors. One publication may be assigned to multiple subject areas if its authors belong to multiple subject areas. For each pair of subject areas, we counted the number of publications that are assigned to both of these subject areas, which is used as a measure of the intensity of the collaboration. For example, an article has two authors; one publishes the majority of his/her publications in ocean engineering and the other in plant science. This article is counted as a collaborative publication between ocean engineering and plant science.

62 The detailed Scopus subject areas are used in the network map. A list of the subject areas can be found in the title of Scopus at *http://www.elsevier.com/_data/assets/excel_doc/0015/91122/title_list.xlsx.*

63 Clusters are identified in Gephi which uses the algorithm to form clusters in a network map discussed in Blondel, V., Guillaume, J., Lambiotte, R., Lefebvre, E. 'Fast unfolding of communities in large networks'. Journal of Statistical Mechanics: Theory and Experiment 10 (2008):1000.

Figure 2.8 *— Network map of Scopus subject areas; for the world; for sustainability science; for 2009-2013. The color of the nodes denotes the clusters. The length of the edges denotes the number of collaborative publications. Nodes with no connection and edges with less than 86 collaborative publications are not shown. Force Atlas 2 algorithm is used for the layout.*

64 For countries such as the USA and the UK, more than 85% of their total publications have at least one author from academia.

65 For more information, see *http://www.unep.org/sbci/*.

66 The important role of Non-Government Organizations (NGOs) is recognized by the UN:" We note the valuable contributions that non-governmental organizations could and do make in promoting sustainable development through their well-established and diverse experience, expertise and capacity." (see *https://sustainabledevelopment.un.org/majorgroups/ngos*). However, NGOs usually do not author a large number of scientific publications and are therefore not listed as a separate sector. NGO-funded research centers are classified into the academic sector.

2.5 Collaboration across sectors

In this section, we explore another aspect of collaboration – the collaboration between different sectors. Academia is no doubt the largest contributor of research in the world.[64] However, the use of research is often realized by practitioners outside of academia (e.g., making policies, curing diseases or developing products). Collaboration across sectors is a way of transferring knowledge from academia to other sectors. Almost all large sustainable development initiatives consist of components that involve stakeholders from various sectors. One example is the United Nations' Sustainable Building and Climate Initiative, which is a partnership of major public and private sector stakeholders in the building sector, working to promote sustainable building policies and practices worldwide.[65]

We classified Scopus institutions into four sectors: academic, medical, corporate and government.[66] To explore the collaboration between these sectors, we identified the top 50 institutions in each sector with the largest number of publications in sustainability science. Table 2.1 shows the top 5 institutions in sustainability science in each sector. We see that many top institutions are from the USA and the UK, but we also see institutions from China, Finland, France and Australia. The top institutions in the academic and government sectors produce the largest number of publications. We also see that for all institutions except for one the FWCI of the publications is above the world average in sustainability science (1.3), confirming the leading position of these top institutions.

What are the sectors?

ACADEMIC

- *University: universities and other institutes that grant undergraduate, graduate and/or Ph.D. degrees as well as engaging in research. Examples: the University of Oxford, the University of Cambridge.*
- *College: institutions that grant undergraduate degrees as well as engaging in research to some extent. Examples of colleges: Trinity Valley Community College, IDRa Costa College, Scottish Agricultural College.*
- *Research institute: organizations whose primary function is to conduct research and may include some educational activities but are not universities. Example: Salk Institute, members of the Max-Planck Society (MPI of Biochemistry and others).*

MEDICAL

- *Medical school: organizations that offer medical degrees as well as engage in research. Examples: Queen's Medical Centre, Harvard Medical School, Brown Medical School. We do not designate dental schools and providers of other health-related degrees as medical schools.*
- *Hospital: organizations whose primary function is to provide health care, although they may also do research. Example: All Saints Hospital, St Mary's Hospital London, and Royal Brompton Hospital.*

CORPORATE

- *Company: commercial entities primarily operating with a profit motive, although some non-profit organizations could potentially be classified as companies. Examples: Unilever, British Broadcasting Corporation, Microsoft Research Cambridge, Royal Bank of Scotland, IBM, Hewlett-Packard.*
- *Law firm: business entities formed by one or more lawyers to engage in the practice of law. Examples: Baker and McKenzie*

GOVERNMENT

- *Government: includes all levels of government as well as United Nations. Example: US Department of Energy, Department for Business, Innovation & Skills, UK.*
- *Military organization: Example: UK Defence Science and Technology Laboratory, US Army Research Laboratory, Weapons and Materials Research Directorate.*

We then plotted the top 50 institutions on a network map (Figure 2.9). Institutions with too few connections were excluded. We see that the majority of the nodes in Figure 2.9 belong to academia (denoted by the color blue). Institutions that collaborate intensively (with a high Salton's index) are plotted close to each other on the chart. On the top of the chart, there are mostly American institutions and the bottom part consists of institutions from the UK, Australia and continental Europe. All Chinese and Japanese institutions are on the top-left corner of the chart. We note that many institutions in the proximity of the Chinese and Japanese institutions in the network concentrate on topics that are covered by the theme *Planet*. This further confirms our previous finding that China and Japan have a research focus on *Planet*.

Most of the top corporate institutions on the chart (denoted by the color pink) are large pharmaceutical companies. They are closely linked to institutions from the USA and the UK. This is consistent with our earlier findings that the USA and the UK's research in sustainability science has a clear focus on *People*, which covers numerous health-related topics. Similarly, the institutions in the medical sector (denoted by the color green) also appear on the right side of the chart. The institutions in the government sector spread across the chart covering at least *Dignity* (e.g., World Bank), *People* (e.g., World Health Organization) and *Planet* (e.g., Japan Agency for Marine-Earth Science and Technology and National Oceanic and Atmospheric Administration). There are also many large national research institutions appearing on the chart (e.g. French National Centre for Scientific Research (CNRS), Commonwealth Scientific and Industrial Research Organization (CSIRO)).[67]

The accompanying table in Figure 2.9 shows the top 10 pairs of partners with the highest intensity of collaboration, indicated by Salton's index. NASA Goddard Space Flight Center in the Government sector and Science Systems and Applications, Inc. in the corporate sector lead with

Table 2.1 *— Top institutions by sector based on the number of publications; for the world; for sustainability science; for 2009-2013*

Institutions	*Publications*	*FWCI*
ACADEMIC		
Harvard University	3,453	2.61
Columbia University	2,715	2.52
Chinese Academy of Sciences	2,674	1.34
University of Washington	2,406	2.48
University of Oxford	2,323	2.50
CORPORATE		
RAND	212	1.74
Landcare Research	203	2.29
Pfizer	173	1.94
GlaxoSmithKline	151	1.85
VTT Technical Research Centre of Finland	138	1.77
GOVERNMENT		
National Oceanic and Atmospheric Administration (NOAA), USA	2,014	2.79
U.S. Department of Agriculture	1,940	2.11
Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia	1,709	2.76
French National Centre for Scientific Research (CNRS)	1,583	2.50
U.S. Geological Survey	1,344	2.57
MEDICAL		
VA Medical Center	1,072	1.79
National Health Service Foundation Trust, UK	300	0.99
Kaiser Permanente	183	2.96
Cincinnati Children's Hospital Medical Center	127	2.15
St. Jude Children Research Hospital	124	1.66

a Salton's index of 0.27.[68] Four of the top 10 pairs are collaborations between one academic institution and one hospital in the same country. The other five pairs consist of one academic institution and one government agency or research center in the same country.

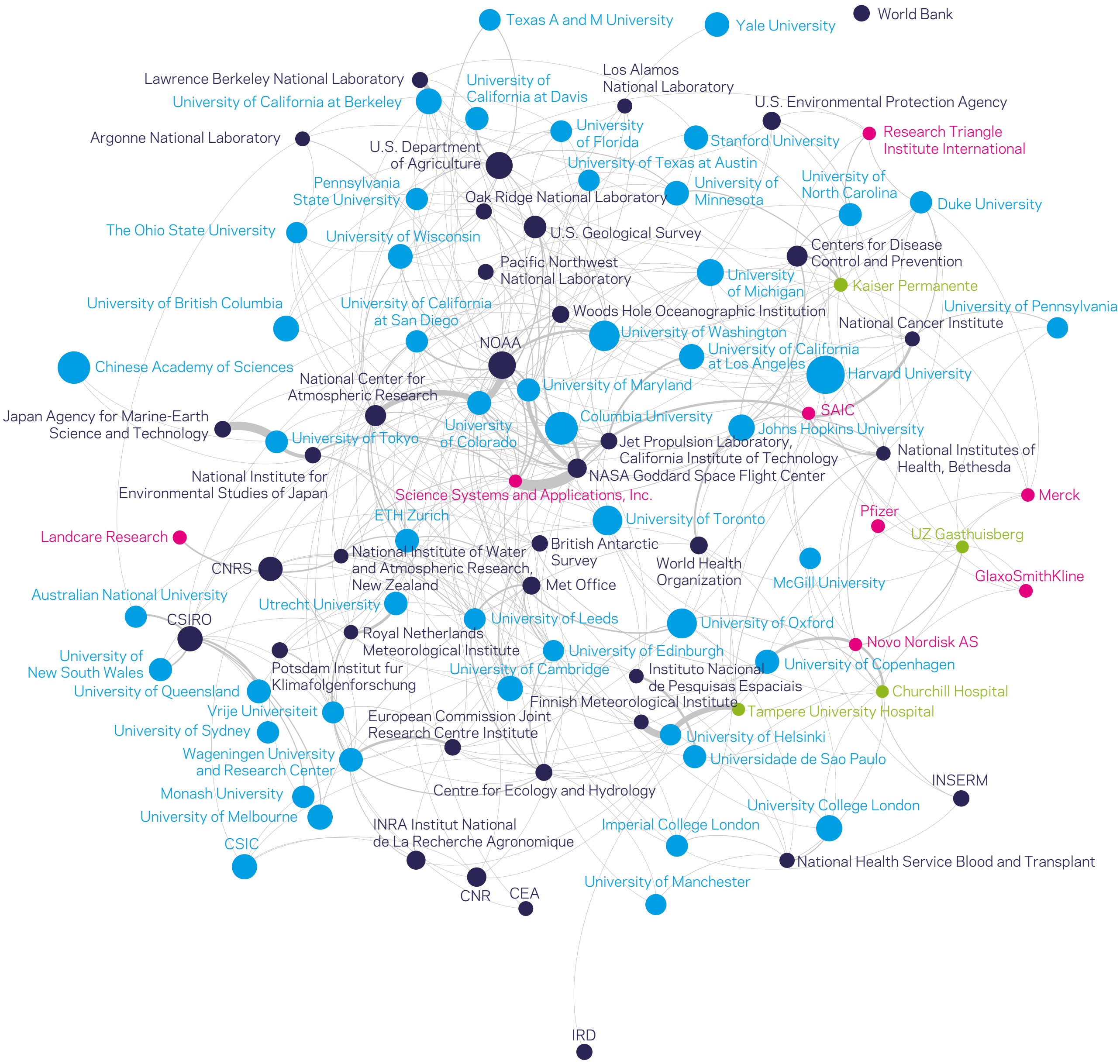


__Figure 2.9__ — Network map of top institutions in each sector; for the world; for sustainability science; for 2009-2013. The size of the nodes denotes the number of the publications of the institution. The color of the nodes denotes the sector of the institution (blue: academic; green: medical; dark blue: government; pink: corporate). The length of the edges denotes Salton's index. Nodes with less than 39 connections and edges with a Salton's index less than 0.025 are not shown. Force Atlas 2 algorithm is used for the layout.

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67 It is not always clear whether these national research institutions belong to academia or government. In this report, we adopt the classifications of institutions from *www.scival.com*.

68 Salton's index ranges from 0, meaning no collaboration, to 1, meaning all publications involving collaboration, and in-between values indicating intermediate similarity or dissimilarity

Top 10 pairs of partners with the highest intensity of collaboration; for the world; for sustainability science; for 2009-2013.

Institution A	*Sector of institution A*	*Institution B*	*Sector of institution B*	*Collaborative publications*	*FWCI*	*Salton's index*
NASA Goddard Space Flight Center	Government	Science Systems and Applications, Inc.	Corporate	72	2.21	0.267
Japan Agency for Marine-Earth Science and Technology	Government	University of Tokyo	Academic	179	2.13	0.207
University of Helsinki	Academic	Finnish Meteorological Institute	Government	105	2.61	0.174
National Oceanic and Atmospheric Administration (NOAA), USA	Government	University of Colorado	Academic	295	3.38	0.169
University of Melbourne	Academic	Royal Children's Hospital	Medical	65	1.58	0.164
University of Sydney	Academic	Royal Prince Alfred Hospital	Medical	34	1.25	0.142
University of Helsinki	Academic	Tampere University Hospital	Medical	41	2.56	0.141
National Center for Atmospheric Research	Government	University of Colorado	Academic	181	4.74	0.137
Lawrence Berkeley National Laboratory	Government	University of California at Berkeley	Academic	120	3.54	0.131
Monash University	Academic	Baker Heart Research Institute	Medical	50	2.24	0.127

INTERVIEW

Richard Horton

Editor-in-Chief, The Lancet

What do you consider the greatest opportunity and challenges in sustainability science?

For me, the greatest and most positive finding of this report is that we are entering a brand new era of policy and politics in global development in a position of strength. There has been substantial growth in volume year on year, which is extremely encouraging, and we see that the quality of papers is above average, indicated by the FWCI measure. That should make us optimistic that the scientific capacity of countries is being brought to bear very positively on the sustainable development agenda. The important thing to note is that we should not take our foot off the accelerator. We should recognize it as strength and something that needs to be developed, and we must not lose this advantage.

How could we develop this strength?

This is where individual country results become important: decisions about investments in sustainability science are made by the countries themselves. Each country needs to know its own strengths. The report shows which countries are doing well, and also where they are relatively weak. When countries have a particular strength, how do you preserve, protect and develop it further? And how do you address the relative weaknesses?

Do the findings of the report raise any other concerns to you?

It is great that we've identified China as a growing country in terms of citations, but I'd be interested in knowing the quality of those citations. It was surprising to me that the US and Japan are below average in terms of growth rate of publications. That is a concern; countries with relative low growth rate in research output should think about where their investments are going in sustainability science.

People talk about North-South collaboration a lot, but if you look at high-low income collaboration, it's still relatively small compared to the other types. That should be a source of concern. It is also important to identify the relatively neglected areas in interdisciplinary research.

Thinking about The Lancet and the area of health, which topics related to sustainable development are key to you?

In my view, areas around maternal child health, infectious disease and chronic diseases and their interplay with poverty, climate and environmental changes, including pollution, are key for sustainable development.

You are working on a special issue of The Lancet on health & sustainable development. How did this start and what do you hope the result will be?

We encourage collaboration between our journals, including our new open access journal The Lancet Global Health. On the sustainable development side, we are *gearing up to fit our work into the SDGs. We wanted to send out a signal of our interest on sustainable development with this special issue. We're expecting some fairly orthodox material around the areas of infectious disease, women and children's health, but what I'm hoping is that we also start to get papers that look at the margins of disciplines and their connections with other disciplines.*

What are the most important factors affecting the development and growth of sustainability science?

First, there are individual elements in the SDGs that are driving the field, the most obvious being climate change. Other areas, especially health, are driving a lot of new research and funds. Second, I think people are gearing up for the SDGs, so it is becoming a more fashionable area for research funding. Third, funders in particular recognize that many of these questions are important but neglected, so they are investing more in these areas.

Which area in your field has been neglected and should be developed more?

We are making progress in areas such as women and children's health. We have made great progress in the last 15 years in reducing mortality of mothers and children in particular, but how do we accelerate this progress? We know for example that lack of nutrition is a major contributor to mother and child deaths, so people are now very interested in how to improve nutrition. This is definitely part of the SDGs. What is driving this area is that we are starting to see cross-cutting issues: it's not just about how you improve women and children's health but also how you change the determinants of women and children's health, which include inequality, nutrition, water and sanitation.

INTERVIEW

Jeffrey D. Sachs

Director of The Earth Institute, Quetelet Professor of Sustainable Development, and Professor of Health Policy and Management at Columbia University. Special Advisor to United Nations Secretary-General Ban Ki-moon on the Millennium Development Goals and Director of the UN Sustainable Development Solutions Network

With the SDGs to be agreed in 2015, what do you see as the opportunities and challenges we are facing for sustainable development?

The big point with the SDGs, the big difference with business as usual, is the whole idea of goal based development. Rather than viewing economic, health or demographic change as a system just to be analyzed, we are looking at these as systems to be managed and directed towards particular outcomes. What I find most interesting with the SDGs is that major objectives are set with a clear time frame. Though it is not a popular phrase, I think it is the right idea, and that is its social engineering. How can society move to meet these objectives within the set time frame? You are not simply observing a system, you are looking at how a system can be managed. For example, with SDG 13 on controlling climate change, how can the energy system be decarbonized in a short period of time? If we look at SDG4 on education, how can a low-income country with only 30% of young people completing secondary education reach the goal of universal completion with quality by the year 2030? These are system engineering questions.

Looking at sustainability science, what are the key questions that have emerged since the term was first coined around 14 years ago?

Actually, I always say to my colleagues that we are not doing sustainability science, but sustainable development. There is a difference: sustainability science was in my interpretation largely created around environmental sustainability. Sustainable development is combining economic development, social inclusion and environmental sustainability as three co-equal pillars. Further, there are two ways to view this subject: one as an analytical science, the second as an approach to social development. It is a bit like the difference between science and engineering – science studies natural systems, while engineering develops artificial systems. Sustainable development of course has to understand natural systems. But it has to understand the economy and social systems dynamics too. In this sense it is more like engineering, in that is trying to create a dynamic of change along desired dimensions.

From your perspective on how the landscape looks, how should the findings of this report be used?

From my perspective there are two further things I would be interested in. I have been advisor to the UN on the Millennium Development Goals (MDGs) for 15 years. I often speak about epistemic communities, meaning socio-psychological entities creating and justifying knowledge around the MDGs' challenges. When I led a project for former UN Secretary-General Kofi Annan on how to achieve the MDGs, I went to find the malariology community.

I went to find the AIDS community. I went to find the maternal and child health community. I also went to find the water and sanitation community. Each of these is a knowledge community. They were extremely helpful on whom to approach and who could address a challenge. But within any scientific, technical or policy community there are still different roles. Some are basic scientists working on natural processes, some are more policy focused, looking at what to do and are more goal oriented. In this context, I like to know what research represents basic science, what aspects are applied, and who are the people doing problem solving work. This knowledge is important.

Further, with The Lancet, which is supporting the present work, The Lancet published the most important compendiums for the MDGs on health. Over the course of a decade or so, they ran major overview articles on best practices in maternal survival, neo-natal survival and other topics. Those were invaluable, because they educated the whole community on how to face this goal. There is a big difference between basic science questions, and say asking how you achieve SDG4 by 2030. The problems are different but also related; you can't do SDG4 without the basic science. Take, for instance, SDG13 on climate change. You could look at climate science, you could look at IPCC Working Group 3 on economic impacts, you could go to engineering journals to look at how to make a grid work with renewables, and you could go to a journal on energy policy to look at how we convert away from our fossil fuel base. There is a natural value chain of knowledge. I think mapping how this range of activities connect and could contribute to problem solving within the SDG framework would be extremely valuable.

Chapter 3 Interdisciplinary Research

This chapter summarizes the findings on interdisciplinary research (IDR) in sustainability science. We investigate to what extent the research in sustainability science is interdisciplinary and identify the most interdisciplinary topics within sustainability science.

3.1 Key findings

SHARE OF THE TOP 10% IDR PUBLICATIONS

6.7%

Around 6.7% of publications in sustainability science in the period 2009-2013 belong to the world's top 10% most IDR publications.

HIGHEST SHARE OF THE TOP 10% IDR PUBLICATIONS

9.4%

India has the highest share of top 10% IDR publications in the period 2009-2013 in sustainability science (9.4%).

Top topics covered by top 10% IDR publications in sustainability science

The three top topics covered by top 10% IDR publications in sustainability science are health and pollution, water and its social and economic implications, and energy, fuels and their economic and environmental impact.

3.2 Interdisciplinary research in sustainability science

Sonnenwald (2006)[69] discusses three types of research collaboration, with a disciplinary focus (e.g., interdisciplinary or monodisciplinary), geographic focus (e.g., international or national collaboration) and organizational and community focus (e.g., academic-corporate collaboration). We discussed the latter two types in Chapter 2 and in this chapter we investigate the interdisciplinary research (IDR) in sustainability science. If we look at the challenges of our planet, none of them are mono-dimensional. Urbanization, scarcity of resources in food, energy, production materials – all relate to society, technology, information and sociology. Therefore, IDR is important in order to address these challenges.

Our measure of IDR is based on the diversity of article references. The further apart in terms of discipline the journals in which the references of an article are published, the more likely the article belongs to IDR. Since it is a citation-based approach, publications that do not have enough references do not obtain an IDR score with our approach; in total, 78% of all Scopus publications in the period 2009-2013 obtain a score with our method.[70] Publications are then ordered according to their IDR scores, and a threshold is set at the 90th percentile to obtain the top 10% IDR worldwide: the 10% of publications with the highest measure of interdisciplinarity in the world for the period 2009-2013.

Figure 3.1 presents the share of the world's top 10% IDR publications of each country's total publications in sustainability science (with an IDR score). On average, only 6.7% of the publications in this research field belong to the world's top 10% IDR. Sustainability science is a field that consists of research from many different subject areas (Figure 2.8 and Appendix E). However, at the article level our measures suggest that these publications do not necessarily integrate many different subject areas. One plausible explanation is that with the changing research landscape and the development of sustainability science as a research field, many research fields that would have been classified previously as interdisciplinary (e.g., environment related research) have now emerged into one discipline (e.g., environmental science). In this case, our measure of IDR would suggest a low level of interdisciplinarity.

Among the top 15 most prolific countries, India, China, Italy and Brazil are leading in the share of world's top 10% IDR out of the countries' total research outputs in sustainability science. Apart from Italy, these countries all grew their research output rapidly in recent decades. Despite their rapid growth in research output, these countries usually have a lower FWCI than research intensive countries such as the USA and the UK (Figure 1.4). However, the picture changes when we look at the intensity of IDR: these countries are more intensively involved in IDR. As a benchmark, when looking at all publications in Scopus in 2013, China and Brazil are leading in this indicator, with 12.3% and 11.0% of their publications in the top 10% IDR respectively.

When talking about China's high share of the top 10% IDR, Dr. Zheng Yonghe, Director of Bureau of Policy for the National Natural Science Foundation of China (NSFC), explained that "the reasons for China's rapid development are diversified, and conclusions can be drawn only by in-depth analysis. Certainly, the Chinese government as well as relevant departments of science and technology have all stressed the importance of IDR over recent years by introducing specific guidelines and policies for pushing forward the IDR progress, playing a significant role in China's IDR development. At present, this is also closely related to a growing number of increasingly complex science issues involving the context of China; solving these issues cannot be achieved by a single discipline, but instead, requires interdisciplinary, which can objectively advance the output of IDR." [71]

What should also be noted in Figure 1.4 is that the share of the top 10% IDR increased between 2009 and 2013 for all countries and the world as a whole, implying a growing trend in IDR in sustainability science.

Is IDR associated with higher citation impact? Figure 3.2 compares the FWCI of publications in sustainability

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69 Sonnenwald, D. H. 'Scientific collaboration'. Annual Review of Information Science and Technology, 41(1) (2007): 643–681.

70 For a detailed description of the methodology in measuring IDR and discussions of its advantages and limitations, see "A Review of the UK's Interdisciplinary Research using a Citation-based Approach: Report to the UK HE funding bodies and MRC by Elsevier", published at *http://www.hefce.ac.uk/pubs/rereports/Year/2015/interdisc/Title,104883,en.html*

71 See *http://www.elsevier.com/connect/interdisciplinary-research-how-do-9-nations-compare*

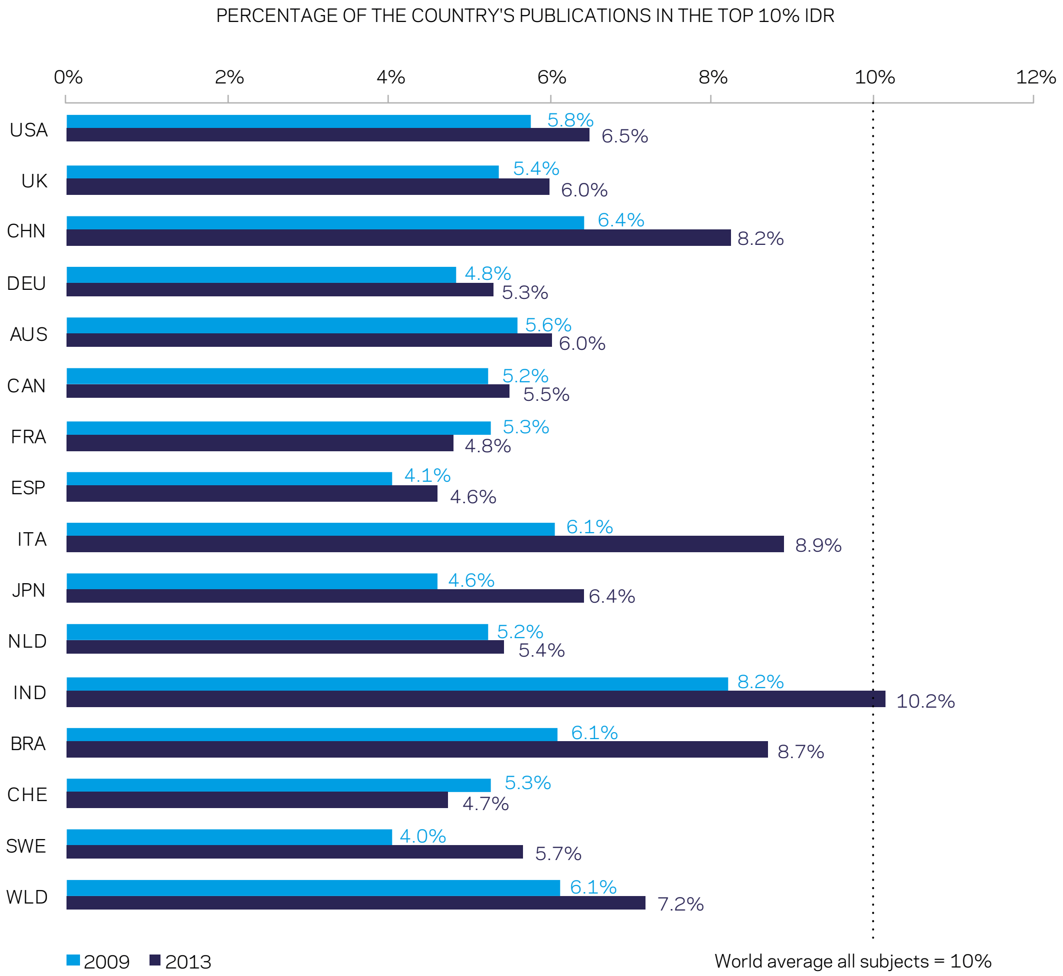


Figure 3.1 — Share of the top 10% most IDR; per country for the top 15 most prolific countries in sustainability science; for sustainability science; 2009 and 2013.

science to that of the top 10% IDR in this field for the top 15 countries and the world as a whole. We see that IDR is associated with lower FWCI. For the world, the FWCI of all publications in sustainability science is 1.30 and that of the top 10% IDR is 1.15.

Various causes have been discussed in the literature that may explain this finding. Bruce et al. (2004)[72] reported the difficulties in managing the coordination and integration of distributed knowledge, and institutional and organizational barriers, such as relatively poor career prospects, discrimination by reviewers in proposals and disproportionately high difficulty in publishing in prestigious journals. Additionally, it may take longer for the citation impact of IDR to be recognized. Wang, Thijs, and Glänzel (2015)[73] found that IDR is associated with lower citation impact in the short term (three years) and higher citation impact in the long term (13 years). Our finding is in line with the first part of the conclusion, since we use a five-year period which is closer to the short term.

72 Bruce, A., Lyall, C., Tait, J., and Williams, R. 'Interdisciplinary integration in Europe: the case of the Fifth Framework programme'. Futures 36 (2004): 457-470.

73 Wang, J., Thijs, B., and Glänzel, W. 'Interdisciplinarity and Impact: Distinct effects of variety, balance, and disparity'. PLoS ONE 10(5) (2015): e0127298. doi:10.1371/journal.pone.0127298.

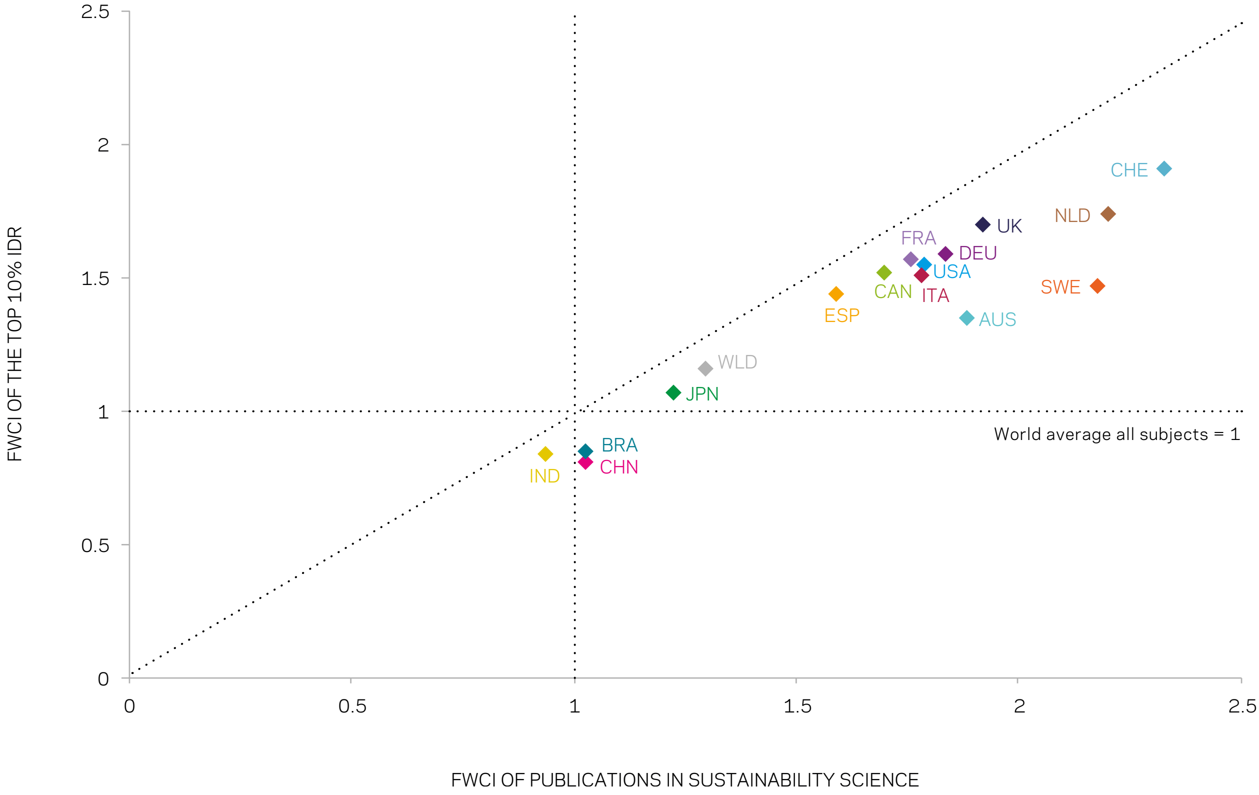


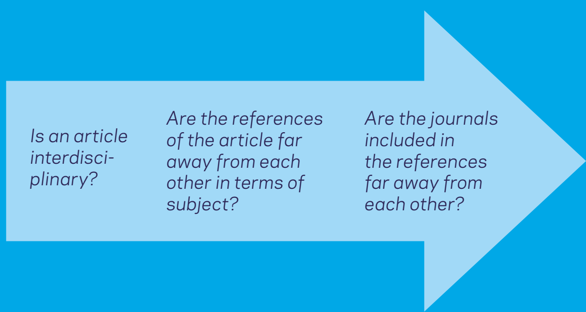
***Figure 3.2** — FWCI of publications in sustainability science and of the top 10% IDR; per country for the top 15 most prolific countries in sustainability science; for sustainability science; for the period 2009-2013.*

Our measure of IDR

In this report, we measure IDR at the article level using a citation-based approach. Since citations take time to accumulate, the most recent publications (2009-2013) have not been cited often. Results that rely on these small numbers of citations will be less precise. Instead, our approach assigns an IDR score to an article based on its references. Articles that reference other articles that are relatively 'far' from each other in terms of discipline are considered more interdisciplinary. If an article references other articles that are relatively 'close' to each other, this suggests that the original article is situated or categorized within a single discipline.

To define how 'far' or 'close' the references of an article are, we look at the journals in which they are published. If these journals are 'far' from each other, these references are also 'far' from each other. If the journals are 'close', we class the references as being 'close'. How, then, do we define whether two journals are 'far' from or 'close' to one another? We count the frequency in which two journals are co-cited in the references of all Scopus publications for a certain period. The more often those journals occur together, the more likely that they are close to each other. The figure below summarizes the logic behind our method.

One major advantage of our approach is the lack of reliance on any pre-defined subject classification to define interdisciplinarity, and is flexible enough to capture the dynamics of the research landscape in which subjects are constantly emerging and changing.



The text in this box is drawn from "A Review of the UK's Interdisciplinary Research using a Citation-based Approach: Report to the UK HE funding bodies and MRC by Elsevier" published at http://www.hefce.ac.uk/pubs/rereports/Year/2015/interdisc/Title,104883,en.html.

3.3 Mapping topics in interdisciplinary research

Which topics are covered most intensively by the IDR publications in sustainability science? To answer this question, we extracted the top 100 key phrases that occur frequently in IDR publications in sustainability science.

To investigate the topics these key phrases present, we plot them in a co-occurrence network map in Figure 3.3. Key phrases that occur together intensively in publications in the top 10% IDR in sustainability science are plotted close to each other. Intensity is indicated by the length of the connecting lines – the closer two nodes are, the more frequently they occur together. In this way, we can identify clusters of key phrases[74] indicated by node color in Figure 3.3. Node size indicates the number of publications containing the key phrase. We should however note that usually large nodes belong to more general terms, such as health and sustainability. When identifying the topic each cluster represents, it is often necessary to pay attention to the smaller and more specific key phrases.

The pink cluster includes many key phrases about pollution and health. Pollution is likely to belong to subject areas such as chemistry and environmental science, and health belongs to medicine-related subject areas. This research area has gained attention from funders and top institutions around the world. For example, the National Institutes of Health in the USA announced a funding opportunity in 2014 that invites applications from institutions in low- and middle-income countries to support an innovative multidisciplinary public health-relevant research project that focuses on an environmental or public health topic.[75] An important component of Harvard University's China project is conducting interdisciplinary studies related to air pollution and greenhouse gases in China, from root causes in the demand for and supply of energy to power its economy, to the chemistry and transport of pollutants in the atmosphere, to their impacts on human health and agriculture.[76]

How were the key phrases selected?

We used the Elsevier Fingerprint Engine to extract distinctive key phrases within sustainability science. The text mining was done by applying a variety of Natural Language Processing techniques to the titles and abstracts of the top 10% IDR publications in sustainability science in order to identify important concepts.

Concepts were matched against a set of thesauri spanning all major disciplines. We first selected 1000 concepts that occur most frequently in the top 10% IDR publications of sustainability science. We then chose 100 concepts based on their relative frequency. Relative frequency is equal to the number of times the concept occurs in the top 10% IDR publications in sustainability science divided by the number of occurrences of the concept in the complete Scopus dataset. A low relative frequency value implies that the concept is a general term such as "method" or "data". We selected 100 concepts with the highest values of relative frequency as the key phrases.

We then calculated how frequently each pair of these key phrases co-occur in the top 10% IDR publications in sustainability science. The more often they occur together, the more likely that they are on closely related topics.

We calculated an index that measures the intensity of the co-occurrences of two key phrases by dividing the number of co-occurrences by the geometric mean of the occurrences of each key phrase.

74 Clusters are identified in Gephi which uses the algorithm to form clusters in a network map discussed in Blondel, V., Guillaume, J., Lambiotte, R., Lefebvre, E. 'Fast unfolding of communities in large networks'. Journal of Statistical Mechanics: Theory and Experiment 10 (2008): 1000.

75 See *http://grants.nih.gov/grants/guide/rfa-files/RFA-TW-14-001.html#sthash.oDo5VK3h.dpuf.*

76 See *http://chinaproject.harvard.edu/.*

77 See *http://depts.washington.edu/mesaair/.*

78 See *https://earth.stanford.edu/eiper.*

79 See *https://mitei.mit.edu/research/laboratory-energy-environment-program.*

80 See *http://wle.cgiar.org/about/.*

81 See *http://www.water.ox.ac.uk/research/water-risk-global-change/.*

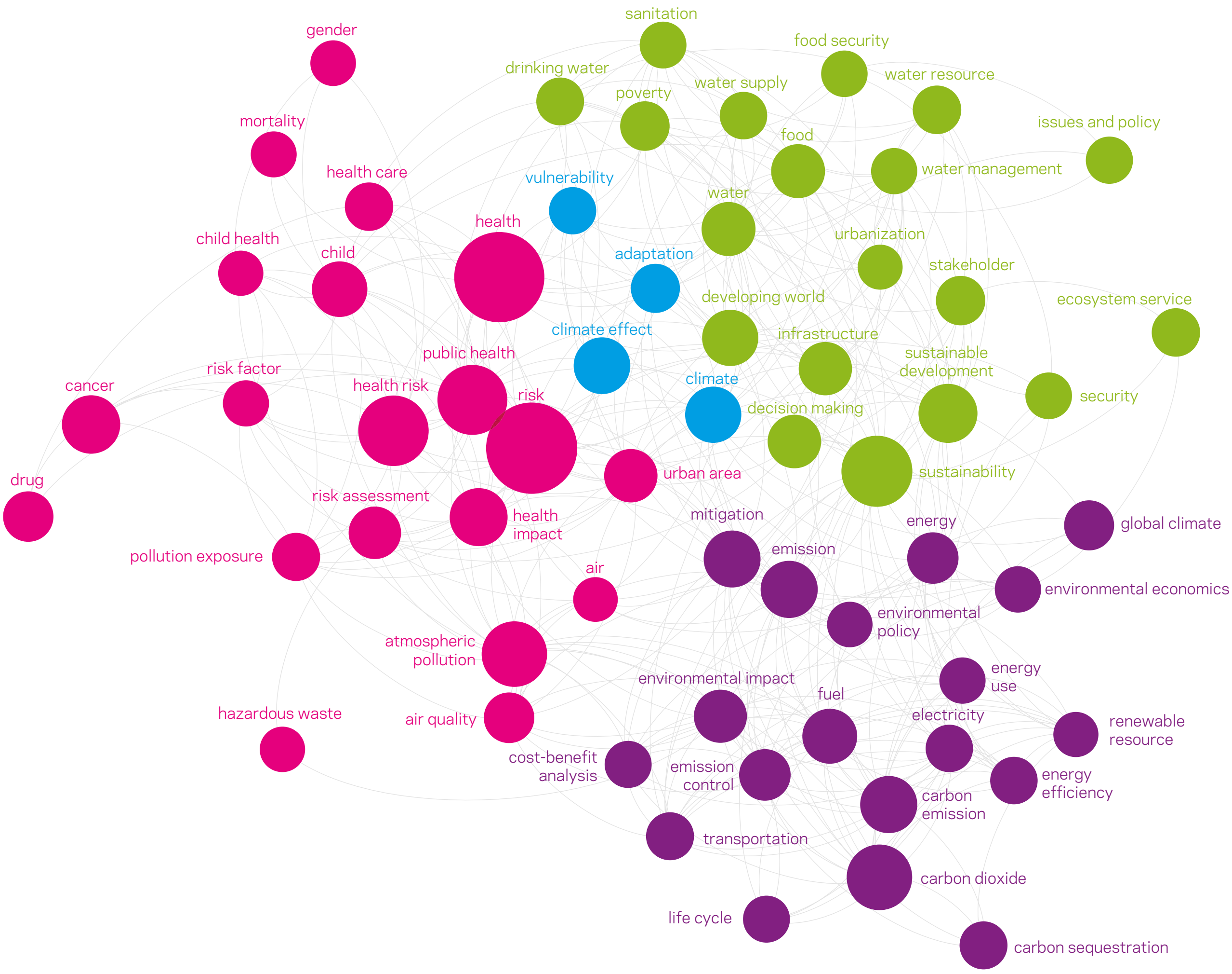


Figure 3.3 *— Co-occurrence map of key phrases in the top 10% IDR publications; for the world; for sustainability science; for the period of 2009-2013. The size of the nodes denotes the number of occurrences of the key phrase. The color of the nodes denotes the clusters. The length of the edges denotes the intensity of co-occurrences of key phrases in the top 10% IDR in sustainability science. Nodes with no connection and edges with the intensity less than 0.076 are not shown. Force Atlas 2 algorithm is used for the layout.*

The University of Washington's Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air) examines the relationship between air pollution exposures and the progression of cardiovascular disease over time.[77]
The purple cluster consists of many key phrases related to energy, fuels and their environmental and economic impact. It is a topic that is likely to include interdisciplinary research covering energy, environmental science and economics. An example of a research programs on this topic is Stanford University's Emmett Interdisciplinary Program in Environment and Resources, which focuses on environmental and resource sustainability challenges.[78] Another example is MIT's Laboratory for Energy & the Environment Program, which tries to address not only the interrelationships between energy and the environment but also the technological, economic, and social aspects of sustainable energy development and use.[79]
The green cluster is related to water and its social and economic implications. Many aspects of water are covered, including infrastructure, water supply and sanitation. It is likely to be a topic that spans engineering, environmental science and social sciences. An example of a research program covering this topic is the Consultative Group for International Agricultural Research (CGIAR)'s research program Water, Land and Ecosystems, which combines the resources of 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO) and national, regional and international partners to develop scalable solutions for reducing poverty, improving food security and maintaining healthy ecosystems.[80] Another example is the University of Oxford's Water Risk and Global Change research program in which system-scale analysis is used to model social, biophysical and infrastructure dynamics related to climate, demographic and economic change at multiple scales.[81]
The identification of the three topics helps us explain the

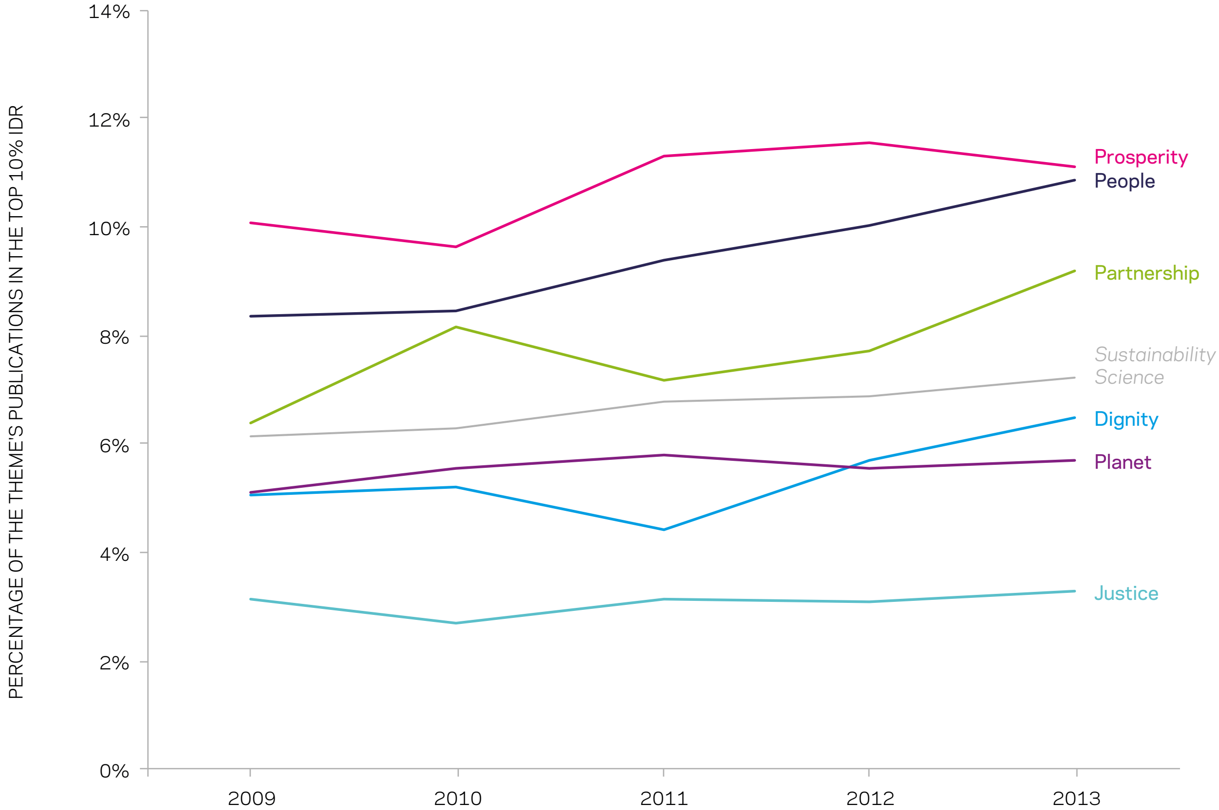


Figure 3.4 *— Share of the top 10% most IDR; for the world; per theme for sustainability science; per year for 2009-2013.*

intensity of IDR in each theme. Figure 3.4 provides the shares of the top 10% IDR by theme. We see that in general there is a higher percentage of publications in *Prosperity* and *People* that belong to the top 10% IDR. *Justice* has the lowest percentage of the six themes. If we map the three IDR topics to the themes, the research on pollution and health (the pink cluster) mostly belongs to *People* (health) and *Prosperity* (pollution). The green cluster (water) mostly belongs to *Prosperity* (water) and, to a lesser extent, to *Dignity* (poverty), *Prosperity* (urbanization) and *Planet* (ecosystem service). The purple cluster (fuels) largely fits into *Prosperity*. Considering these are the top topics in IDR, there is no surprise that *Prosperity* and *People* have the highest share of the top 10% IDR.

"[...] Most of the issues above fit into the theme of People, but will require an extremely interdisciplinary approach in order to identify solutions. [...] Healthcare contains a narrow part of the set of capabilities that will be needed. That is why understanding the interdisciplinary nature of sustainability research is important, and this report creates a framework for studying it."

*— Ashish K. Jha,
Harvard Global Health Institute*

"It was no surprise the justice theme had low levels of interdisciplinary research. Much of my work on the concept of Rule of Law is to help people, including within the legal community, to understand the multitude of connections with other areas, such as prosperity, development or economics."

— Ian McDougall, LexisNexis L&P

INTERVIEW

Kazuhiko Takeuchi

Senior Vice-Rector of the United Nations University and Assistant Secretary-General of the United Nations, as well as Director and Professor of the Integrated Research System for sustainability science (IR3S) at the University of Tokyo

What do you consider to be the greatest challenges and opportunities in sustainability science?

One of the challenges would be that the existing academic disciplines are so strong and are trying to keep their own identities, so it is very difficult for us to allocate human and financial resources for the development of sustainability science. For example, at the University of Tokyo we established a sustainability science initiative, the Integrated Research System for Sustainability Science (IR3S), 13 years ago, but it is still a very small group. Our challenge is to find ways of developing sustainability science research with limited resources.

The existing funding mechanism is another constraint, but the fundamental limitation is human resources. Most of the scientists dealing with sustainability science only hold temporary positions, but there are opportunities because sustainability science is developing. For example, in Vietnam the new Vietnam–Japan University Graduate School of Sustainability Science will be established. And in Africa, we have very good collaboration with the Stellenbosch University Sustainability Institute. Collaboration and networking are important because they will give us opportunities to influence society through the United Nations and international negotiation processes. I am pleased that in the last decade or so sustainability science has evolved to become a mainstream part of society.

What do you think are the most important scientific outcomes contributed by sustainability science in the last 15 years?

I think that the concept of resilience and its application had an impact on society. This is particularly important in Japan: how can we really use natural capital to rebuild disaster-affected areas? Previously, we had been discussing sustainability science, what it is and how we could define it, but now we are more concerned about how we can really apply the sustainability science approach to transform our society, and how a scientific approach can solve real problems in society.

In your opinion, how does the concept of planetary boundaries affect the development of sustainability science?

I think the integration of the different aspects of global sustainability is important. Climate scientists are only discussing climate change, biologists only focus on biodiversity, and economists only talk about the social dimension of global sustainability. These discussions need to be coordinated. The physical, biological, chemical, social and cultural aspects of the planet need to be integrated. The concept of planetary boundaries, proposed in 2009 by a group of 29 researchers led by Johan Rockström of Stockholm Resilience Center, is impressive because it can visually show us the relationships between the different planetary problems.

Typically, Japan's international collaboration rate is around 20-25%; in sustainability science it's higher, at 35%. Is this because the topic is international by definition?

I would say that our business is a very globalized family business. We are very small in our numbers in the scientific community, therefore we need to find out collaborators not only within our country, but also in other countries; otherwise we would not be able to develop our work. For example, in order to discuss the relationship between sustainability and resilience, it is better to speak with the Stockholm Resilience Center. If we talk about multi-stakeholder involvement, for example, we could have a very good discussion with Indiana University on "new commons".

Additionally, one of the approaches proposed by the Future Earth research initiative as one of the major directions of the International Council for Science (ICSU) is to be cross-disciplinary. Sustainability science should involve trans-disciplinary efforts, not just interdisciplinary efforts. When we talk about the trans-disciplinary approach, we also need to consider the relationship between academia and society; we need to break the barrier between the academic community and real society.

What is your opinion on North-South collaboration in sustainability science?

In Japan, I am now one of the leaders of a Japan Science and Technology Agency (JST) / Japanese International Cooperation Agency (JICA) project on the possibility of collaboration between the global North and South — as part of the so-called SATREPS program. One of the important tasks we identified was to establish similar funding systems we can see in Japan and the US. What is also important for North–South collaboration is building research capacity in developing countries. One of the important JST themes is to support education for people in their own countries. So for example, JICA decided to support the Vietnam–Japan University Graduate School of Sustainability Science and encouraged researchers to stay in Vietnam and increase their ability to solve the problems they are facing there.

If you look 5 or 10 years ahead, what do you hope to achieve?

2020 is quite an important year when we talk about the achievement of various targets, and also for looking further forward, towards the year 2030. 2020 will be the year when we need to judge whether we are really moving towards sustainability. Of course, we are hoping that we can transform our society towards sustainability. The year 2050 should be a turning point of society in terms of greenhouse gas emissions, biodiversity loss and chemical pollution and so on, as already indicated by the planetary boundaries concept.

INTERVIEW

Mark Gold

Associate Vice Chancellor of Environment and Sustainability
University of California at Los Angeles

What do you consider the most important factors affecting how sustainability science has developed in your country and region?

Los Angeles County is the most populous county in the United States and consists of 88 individual cities. It is a unique habitat with incredible biodiversity, which presents both opportunities and challenges. A first step on the path to sustainability is benchmarking. After nearly two years of gathering and analyzing data, the Institute of the Environment and Sustainability at UCLA has developed an Environmental Report Card for the County of Los Angeles, the first of its kind in the nation for a major metropolitan area.

This report is a similar benchmark, in this case of scholarly communication in the field. The mapping provides a starting point for understanding sustainability research activity and simultaneously raises a lot of questions. Embedded in each broad theme, Planet, for example, there is a lot of disciplinary detail that can be analyzed further, and in conjunction with the wealth of information currently available in the grey literature.

What do you consider to be the greatest challenges and opportunities in sustainability science?

The challenges are considerable and multi-faceted. The Sustainable LA Grand Challenge at UCLA has identified three broad goals for the Los Angeles region: to use exclusively renewable energy and local water by 2050 while enhancing ecosystem health including no loss of native biodiversity. Also, enhancing quality of life is embedded in the Sustainable LA: Thriving in a Hotter LA Grand Challenge.

In addition to achieving these concrete objectives, a critical opportunity and challenge is ensuring the right stakeholders are included. At the genesis of the project 150 UCLA faculty expressed interest in getting involved; such immediate and collective agreement is unusual in a university setting. The fact that so many were interested was great to see. The effort is campus-wide and not seen through the lens of any single institute. One of the most critical work products will be the completion of a blueprint by 2020, based on research that will be completed by then, on recommendations for how to reach these final ambitious sustainability goals. This will not be merely a series of papers that gets published; it will be a concerted effort to work across numerous sectors and with collaborating stakeholders in government, business, NGOs and other academic institutions.

What steps do you think the field should take to resolve these issues and effect greater engagement with the public?

Simply doing the research is not enough; we must ensure that what gets done has an effect on Los Angeles and beyond. We seek to develop not only research plans but education and action plans. To achieve impact we must cultivate partnerships on both the research side and policy side. This report seeks a similar level of engagement with policy makers through its connection with the adoption of the UN Sustainable

Development Goals at a global level. A further value of the report is that it leads academics to take a critical look at sustainability research, education, practices, and services at a university and community scale.

What societal or ethical issues do you think will influence sustainability science priorities and applications in the future?

We are seeing the transformation of applied sustainability research starting to occur in such a large way; for example, there has been explosive growth in the number of sustainability majors at universities. At UCLA we have 400 faculty doing work related to the environment and sustainability and we provide more than 600 related classes to our students. Commitments to active research in the field and work with organizations like the Environmental Protection Agency (EPA), local government, environmental groups or environmental consulting firms is becoming more commonplace; this acknowledges that one of the most critical goals of sustainability research is impacting the quality of life in communities.

Are there any aspects of the present report that you think should be further explored in relation to Europe/ APAC/ Africa/America or on a global level?

The report sections on North-South collaboration are particularly important. UCLA is very proud to be in partnership with multiple global organizations; for example UCLA and the International Institute of Tropical Agriculture (IITA) are leading a multi-institutional initiative that just launched the Congo Basin Institute (CBI) in Cameroon. Almost any sustainability issue on the planet is present there. The Professor Tom Smith-led effort will involve interdisciplinary research, education, training and technology development focused on critical issues facing the Congo Basin with implications for both the developing and developed world: climate change and its impacts, water and food security, and human and animal health.

We are working with our partners to help Cameroon develop a rainforest protection project under the United Nations program known as REDD, or Reducing Emissions from Deforestation and Forest Degradation. The endeavor, if it goes forward, will be the largest REDD project in Africa to date. The area includes the Dja Reserve and surroundings and will encompass an area the size of Maine.

There is a further dimension to North-South collaboration: we are making a difference locally and whatever we do in LA can be applicable in mega-cities everywhere. Smog reduction is one example of transferable lessons we can share with other countries and institutions.

Thinking about the future of sustainability research globally, where do you think we will be in 5 and 10 years' time?

It is already rewarding to see the current Los Angeles Mayor Eric Garcetti push to achieve an 80% reduction in greenhouse gas emissions by 2050. Our University of California President, Janet Napolitano, would like to see the UC system carbon-neutral by 2025. In addition, Governor Brown and the state legislature are on the cusp of approving a raft of precedent setting climate change legislation on renewables, reduction in fossil fuel use and greenhouse gas reduction. Grand Challenges should be based on stretch goals that will really make a beneficial difference and it is great to see the region and the state moving in the right direction.

[The participants gratefully acknowledge discussions with Dr. Casandra Rauser, Director, Sustainable LA Grand Challenge at UCLA.]

Chapter 4 Conclusions and Discussions

This chapter summarizes the key findings of the study and discusses how the current analysis may benefit different stakeholders in the near future.

4.1 Conclusions and discussions

As the first of a series of activities that aim to provide valuable insights into the global research landscape surrounding the UN Sustainable Development Goals, this report, conducted by Elsevier in collaboration with SciDev.Net, contributes to the understanding of sustainability science as a research field and the dialogue between science and society in sustainable development. In this relatively young field, this study establishes a baseline, both in the definition and the understanding of sustainability science, from which we may follow its progression and trajectory.

The report documents the rapid growth in sustainability science in recent years, doubling the annual average growth rate of research indexed in Scopus during the same period. Sustainability research is conducted in developed countries as well as in emerging and developing nations. The research output is both global and collaborative by definition. For countries such as the UK and Germany, close to half of their publications in sustainability science involve international collaboration. In several countries, in particular China and Japan, collaboration rates in sustainability science exceed the international collaboration rates of the country's research overall. Upon examination of global research networks in sustainability science, Africa is closely linked to the USA, Canada and Western Europe. Beyond geography, the study demonstrates collaboration across the sectors of academia, government, industry and medicine. And academia and industry are strongly connected in health-related research. The collaborative efforts of researchers result in higher impact research, underscored by citation impact 30% higher than the world average.

The report provides a unique overview of the current status of sustainability science as a research field; identifying the countries, institutions, themes and topics to support the broad agenda of sustainable development. We hope that the data and analysis will benefit researchers, funders and policy makers in their research activities, fund management and policy design. It will help researchers think tactically about where there are gaps in knowledge and networks.

> *"Bibliometric studies will also help researchers acquire a more comprehensive understanding of the status of research on sustainable development and identify their peers who are conducting similar research."*
>
> *— Yishan Wu, Chinese Academy of Science and Technology for Development*

For institutions, the results may be used to identify research strengths within the themes in sustainability science, potential collaborators in academia and other sectors, and more importantly to identify gaps between research topics and societal needs.

> *"There is, or should be, a link between what scientists think is important and what society thinks is important. This report can help to establish that. It is important to examine how we collaborate across institutions and, more importantly, across disciplines and sectors over time."*
>
> *— Joshua Tewksbury, College of the Environment, University of Washington*

For funders, the key findings bring insights into the global research portfolio in sustainability science. As discussed in some of the interviews in this report, one of the major challenges is resource allocation. Effective funding of sustainability science requires the aggregation of knowledge from existing traditional discipline-based organizational structures combined with a geopolitical view. The results of this report may provide evidence to funders of the results and impact of their contributions at the country-level for example, and identify areas needing resources and further development.

For policy makers, it is important to understand that the development of science, technology and innovation is critical to sustainable development. Policy that stimulates research to address the challenges in sustainable development is essential. It is equally critical to include contributors from the research community in the policy making process. This report maps the research underlying sustainable development to the UN SDGs, and helps the policy makers to identify key contributors in the research community.

> *"To achieve impact we must cultivate partnerships on both the research side and policy side. This report seeks a similar level of engagement with policy makers through its connection with the adoption of the UN Sustainable Development Goals at a global level."*
>
> *— Mark Gold, University of California at Los Angeles*

This initial study raises further questions. For example, the strong showing of private sector health-related firms in the collaboration network warrants deeper examination. Are lower rates of IDR in sustainability counter intuitive? What factors underlie the low level of collaboration between the North and the South? How is the body of sustainability science changing and developing over time? We look forward to exploring these and more questions in future studies, in collaboration with the research community and related practitioners, to contribute to the broad dialogue between science and society in sustainable development.

Appendices

Appendix A
Project Team, Steering Committee, Experts, and Acknowledgements

Project steering committee

Elsevier: M'hamed Aisati, Youngsuk Chi, Nick Fowler, Hannfried von Hindenburg, David Ruth, Philippe Terheggen

SciDev.Net: Nick Perkins

Core project team

Project lead
Coralie Bos

Analytics lead
Lei Pan

Other core team members: Kevin Agnew, Ludivine Allagnat, Marcia Balisciano, Ann Gabriel, Shereen Hanafi, Richard Horton, Judith Kamalski, Xiaoling Kang, Anders Karlsson, Iris Kisjes, and Elaine van Ommen Kloeke

Other project team members

Stephane Berghmans, Sandra Broerse, Joe d'Angelo, Pamela Das, Ian Evans, Holly Falk-Krzesinski, Brad Fenwick, Sophia Katrenko, Michiel Kolman, Georgin Lau, Chrysanne Lowe, Kay McArdle, Jesse Mudrick, Melanie Thomson, Ylann Schemm, Mark Siebert

Subject experts

Arun Agarwal

Professor at the School of Natural Resources & Environment at the University of Michigan, USA, and Editor-in-Chief, World Development

Jon Barnett

Professor and Australian Research Council Future Fellow in the School of Geography at Melbourne University, Australia. Lead Author for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Co-Editor Global Environmental Change

Matt DeLisi

Editor-in-Chief, Journal of Criminal Justice. Professor and Coordinator, Criminal Justice Studies, Affiliate, Center for the Study of Violence, Iowa State University, USA

Andy Haines

Professor of Public Health and Primary Care with a joint appointment in the Department of Social and Environmental Health Research and in the Department of Population Health at the London School of Hygiene and Tropical Medicine, London, UK. Chair Planetary Health Commission.

Richard Horton

Editor-in-Chief, The Lancet

Hetal Jain

Sustainability Program Manager, Department of Transportation, USA

Brent Kurapatskie

Sustainability Program Manager, Department of Transportation, USA

Takako Izumi

Managing Associate Professor, Office of the President (Promotion of International Disaster Science), International and Regional Cooperation Office, International Research Institute of Disaster Science (IRIDeS), Tohoku University, Japan

Ilan Kelman

Institute for Risk and Disaster Reduction / Institute for Global Health, University College London, UK

Trudie McNaughton

Pro Vice-Chancellor, Equity Equity Office – Te Ara Tautika The University of Auckland, New Zealand

Debbie Niemeier

Professor, Department of Civil and Environmental Engineering, University of California, Davis, USA

Hideyuki Mori

President, Institute for Global Environmental Strategies (IGES), Japan

Ashok Pandey
Head, Centre for Biofuels and Biotechnology Division, CSIR-National Institute for Interdisciplinary Science and Technology at Trivandrum, India

Dennis Wichelns
Editor-in-Chief, Water Resources & Rural Development. Co-Editor in Chief, Agricultural Water Management

Alexander Zehnder
Scientific Director Water Resources, Alberta Innovates – Energy and Environment Solutions (AI-EES), Edmonton, Canada; Founder and Director, Triple Z Ltd.; Visiting Professor Nanyang Technological University (NTU), Singapore

Eric Zusman
Area Leader/Principal Researcher Integrated Policies for Sustainable Societies, Institute for Global Environmental Strategies, Japan

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Appendix B
Country Codes and Income Classes

Country	Code	Class
Afghanistan	AFG	*Low*
Albania	ALB	*Upper-middle*
Algeria	DZA	*Upper-middle*
American Samoa	ASM	*Upper-middle*
Andorra	AND	*High*
Angola	AGO	*Upper-middle*
Antigua and Barbuda	ATG	*High*
Argentina	ARG	*Upper-middle*
Armenia	ARM	*Lower-middle*
Aruba	ABW	*High*
Australia	AUS	*High*
Austria	AUT	*High*
Azerbaijan	AZE	*Upper-middle*
Bahamas, The	BHS	*High*
Bahrain	BHR	*High*
Bangladesh	BGD	*Low*
Barbados	BRB	*High*
Belarus	BLR	*Upper-middle*
Belgium	BEL	*High*
Belize	BLZ	*Upper-middle*
Benin	BEN	*Low*
Bermuda	BMU	*High*
Bhutan	BTN	*Lower-middle*
Bolivia	BOL	*Lower-middle*
Bosnia and Herzegovina	BIH	*Upper-middle*
Botswana	BWA	*Upper-middle*
Brazil	BRA	*Upper-middle*
Brunei Darussalam	BRN	*High*
Bulgaria	BGR	*Upper-middle*
Burkina Faso	BFA	*Low*
Burundi	BDI	*Low*
Cabo Verde	CPV	*Lower-middle*
Cambodia	KHM	*Low*
Cameroon	CMR	*Lower-middle*
Canada	CAN	*High*
Cayman Islands	CYM	*High*
Central African Republic	CAF	*Low*
Chad	TCD	*Low*
Chile	CHL	*High*
China	CHN	*Upper-middle*
Colombia	COL	*Upper-middle*
Comoros	COM	*Low*
Congo, Dem. Rep.	ZAR	*Low*
Congo, Rep.	COG	*Lower-middle*
Costa Rica	CRI	*Upper-middle*
Côte d'Ivoire	CIV	*Lower-middle*
Croatia	HRV	*High*
Cuba	CUB	*Upper-middle*
Cyprus	CYP	*High*
Czech Republic	CZE	*High*
Denmark	DNK	*High*
Djibouti	DJI	*Lower-middle*
Dominica	DMA	*Upper-middle*
Dominican Republic	DOM	*Upper-middle*
Ecuador	ECU	*Upper-middle*
Egypt, Arab Rep.	EGY	*Lower-middle*
El Salvador	SLV	*Lower-middle*
Equatorial Guinea	GNQ	*High*
Eritrea	ERI	*Low*
Estonia	EST	*High*
Ethiopia	ETH	*Low*
Faeroe Islands	FRO	*High*
Fiji	FJI	*Upper-middle*
Finland	FIN	*High*
France	FRA	*High*
French Polynesia	PYF	*High*
Gabon	GAB	*Upper-middle*
Gambia, The	GMB	*Low*
Georgia	GEO	*Lower-middle*
Germany	DEU	*High*
Ghana	GHA	*Lower-middle*
Greece	GRC	*High*
Greenland	GRL	*High*
Grenada	GRD	*Upper-middle*
Guam	GUM	*High*
Guatemala	GTM	*Lower-middle*
Guinea	GIN	*Low*
Guinea-Bissau	GNB	*Low*
Guyana	GUY	*Lower-middle*
Haiti	HTI	*Low*
Honduras	HND	*Lower-middle*
Hong Kong SAR, China	HKG	*High*
Hungary	HUN	*Upper-middle*
Iceland	ISL	*High*
India	IND	*Lower-middle*
Indonesia	IDN	*Lower-middle*
Iran, Islamic Rep.	IRN	*Upper-middle*
Iraq	IRQ	*Upper-middle*
Ireland	IRL	*High*
Israel	ISR	*High*
Italy	ITA	*High*
Jamaica	JAM	*Upper-middle*
Japan	JPN	*High*
Jordan	JOR	*Upper-middle*
Kazakhstan	KAZ	*Upper-middle*
Kenya	KEN	*Low*

Kiribati	KIR	*Lower-middle*
Korea, Dem. Rep.	PRK	*Low*
Korea, Rep.	KOR	*High*
Kuwait	KWT	*High*
Kyrgyz Republic	KGZ	*Lower-middle*
Lao PDR	LAO	*Lower-middle*
Latvia	LVA	*High*
Lebanon	LBN	*Upper-middle*
Lesotho	LSO	*Lower-middle*
Liberia	LBR	*Low*
Libya	LBY	*Upper-middle*
Liechtenstein	LIE	*High*
Lithuania	LTU	*High*
Luxembourg	LUX	*High*
Macao SAR, China	MAC	*High*
Macedonia, FYR	MKD	*Upper-middle*
Madagascar	MDG	*Low*
Malawi	MWI	*Low*
Malaysia	MYS	*Upper-middle*
Maldives	MDV	*Upper-middle*
Mali	MLI	*Low*
Malta	MLT	*High*
Marshall Islands	MHL	*Upper-middle*
Mauritania	MRT	*Lower-middle*
Mauritius	MUS	*Upper-middle*
Mexico	MEX	*Upper-middle*
Micronesia, Fed. Sts.	FSM	*Lower-middle*
Moldova	MDA	*Lower-middle*
Monaco	MCO	*High*
Mongolia	MNG	*Lower-middle*
Montenegro	MNE	*Upper-middle*
Morocco	MAR	*Lower-middle*
Mozambique	MOZ	*Low*
Myanmar	MMR	*Low*
Namibia	NAM	*Upper-middle*
Nepal	NPL	*Low*
Netherlands	NLD	*High*
New Caledonia	NCL	*High*
New Zealand	NZL	*High*
Nicaragua	NIC	*Lower-middle*
Niger	NER	*Low*
Nigeria	NGA	*Lower-middle*
Northern Mariana Islands	MNP	*High*
Norway	NOR	*High*
Oman	OMN	*High*
Pakistan	PAK	*Lower-middle*
Palau	PLW	*Upper-middle*
Panama	PAN	*Upper-middle*
Papua New Guinea	PNG	*Lower-middle*
Paraguay	PRY	*Lower-middle*
Peru	PER	*Upper-middle*
Philippines	PHL	*Lower-middle*
Poland	POL	*High*
Portugal	PRT	*High*
Puerto Rico	PRI	*High*

Qatar	QAT	*High*
Romania	ROU	*Upper-middle*
Russian Federation	RUS	*High*
Rwanda	RWA	*Low*
Samoa	WSM	*Lower-middle*
San Marino	SMR	*High*
São Tomé and Principe	STP	*Lower-middle*
Saudi Arabia	SAU	*High*
Senegal	SEN	*Lower-middle*
Serbia	SRB	*Upper-middle*
Seychelles	SYC	*Upper-middle*
Sierra Leone	SLE	*Low*
Singapore	SGP	*High*
Slovak Republic	SVK	*High*
Slovenia	SVN	*High*
Solomon Islands	SLB	*Lower-middle*
Somalia	SOM	*Low*
South Africa	ZAF	*Upper-middle*
Spain	ESP	*High*
Sri Lanka	LKA	*Lower-middle*
St. Kitts and Nevis	KNA	*High*
St. Lucia	LCA	*Upper-middle*
St. Vincent and the Grenadines	VCT	*Upper-middle*
Sudan	SDN	*Lower-middle*
Suriname	SUR	*Upper-middle*
Swaziland	SWZ	*Lower-middle*
Sweden	SWE	*High*
Switzerland	CHE	*High*
Syrian Arab Republic	SYR	*Lower-middle*
Tajikistan	TJK	*Low*
Tanzania	TZA	*Low*
Thailand	THA	*Upper-middle*
Timor-Leste	TLS	*Lower-middle*
Togo	TGO	*Low*
Tonga	TON	*Upper-middle*
Trinidad and Tobago	TTO	*High*
Tunisia	TUN	*Upper-middle*
Turkey	TUR	*Upper-middle*
Turkmenistan	TKM	*Upper-middle*
Turks and Caicos Islands	TCA	*High*
Tuvalu	TUV	*Upper-middle*
Uganda	UGA	*Low*
Ukraine	UKR	*Lower-middle*
United Arab Emirates	ARE	*High*
United Kingdom	UK	*High*
United States	USA	*High*
Uruguay	URY	*High*
Uzbekistan	UZB	*Lower-middle*
Vanuatu	VUT	*Lower-middle*
Venezuela, RB	VEN	*Upper-middle*
Vietnam	VNM	*Lower-middle*
Virgin Islands (U.S.)	VIR	*High*
Yemen, Rep.	YEM	*Lower-middle*
Zambia	ZMB	*Lower-middle*
Zimbabwe	ZWE	*Low*

Appendix C
Mapping the SDGs and the Six Essential Elements/Themes

Essential Elements/themes	*SDGs*
1. Dignity: to end poverty and fight inequalities	Goal 1: End poverty in all its forms everywhere Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 10: Reduce inequality within and among countries
2. People: to ensure healthy lives, knowledge and the inclusion of women and children	Goal 3: Ensure healthy lives and promote well-being for all at all ages Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all Goal 5: Achieve gender equality and empower all women and girls
3. Prosperity: to grow a strong, inclusive and transformative economy	Goal 6: Ensure availability and sustainable management of water and sanitation for all Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable Goal 12: Ensure sustainable consumption and production patterns
4. Planet: to protect our ecosystems for all societies and our children	Goal 13: Take urgent action to combat climate change and its impacts Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
5. Justice: to promote safe and peaceful societies and strong institutions	Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
6. Partnership: to catalyze global solidarity for sustainable development	Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development

Appendix D
Scopus Search Conditions

THEME DIGNITY

The publications need to satisfy the following conditions:

1. Contain at least one of the keywords or combinations of keywords in abstract, title or keywords:

agricultural development
(agricultural production AND sustainab*)
child labor
child mortality
children's health
development aid
distributional effect
(educational attainment AND sustainab*)
endowment
(food AND aid)
(food policy AND sustainab*)
food price
(food security AND sustainab*)
(hunger AND sustainab*)
income growth
income inequality
income shock
land ownership
land reform
land right
land tenure
malnutrition
poverty alleviation
poverty determinant
poverty line
poverty reduction
(reform program* AND sustainab*)
(rural development AND sustainab*)
rural finance
rural poverty
(safety net AND sustainab*)
small farmer
smallholder

2. Belong to one of the following Scopus subject areas: social sciences, economics, econometrics & finance, business, management & accounting, multidisciplinary, and does not belong to medicine.

THEME PEOPLE

The publications need to satisfy at least one of the following two conditions:

1. Satisfy a, b and c below:
   a. Contain at least one of the keywords or combinations of keywords in abstract, title or keywords:

AIDS
cancer
cardiovascular disease
child mortality
chronic respiratory disease
diabetes
drug abuse
health finance
health risk
hepatitis
HIV Infection
household accident
intersex
lesbian
malaria
maternal mortality
mental health
neonatal mortality
planned abortion
post natal depression
premature mortality
reproductive health
sexually transmitted disease
spontaneous abortion
tobacco use
traffic accident
transgender
tropical disease
tuberculosis
unplanned pregnancy
vaccine
(victim AND crime)
violence
water-borne disease

   b. Contain at least one of the following keywords in abstract, title or keywords: development, sustainab*, millennium, goal, target, indicator.
   c. Belong to at least one of the Scopus subject areas: obstetrics and gynaecology, health policy, endocrinology, diabetes & metabolism, cardiology & cardiovascular medicine, psychiatry & mental health, public health, environmental & occupational health, infectious diseases,

pediatrics, perinatology & child health, economics, econometrics & finance, social sciences, business, management & accounting, environmental science.

2. Contain at least one of the keywords or combinations of keywords in abstract, title or keywords:

child labor
child schooling
demand for schooling
domestic violence
early marriage
employment equity
(empowerment AND women)
family planning
female education
female labor force participation
gender disparity
gender gap
gender identity
gender inequality
gender wage gap
intra-household allocation
occupational segregation
parental education
PROGRESA
(reproductive technology AND access)
school attendance
school enrollment
unpaid work
wage differential
women's employment

THEME PROSPERITY

The publications need to contain at least one of the keywords or combinations of keywords in abstract, title or keywords:

2000 Watt society
(air pollution AND (transportation OR city OR cities))
(atmospheric pollution AND (transportation OR city OR cities))
(cities AND gentrification OR (city AND gentrification))
clean city
(congestion AND (transportation OR city OR cities AND sustainab*))
criteria pollutant
decentralized energy supply
decentralized water supply
(drinking water AND (sustainab*))
economic geography
(employment protection AND (sustainab* OR development))
(energy conservation AND urban area)
energy consumption per capita
energy efficiency AND sustainab*
energy footprint
(energy security AND sustainab*)
energy subsidy
environmental justice
(finance AND sustainab*)
(global warming AND (transportation OR city OR cities))
(greenhouse gas AND (transportation OR city OR cities))
hazardous waste
inclusive growth
(industrial development AND sustainab*
industrial growth
(industrialization AND (sustainab* OR development))
(informal employment AND (sustainab* OR development))
informal sector
(infrastructural development AND sustainab*)
(infrastructure investment* AND sustainab*)
integrated water management
(labor market institution AND (sustainab* OR development))
(land use AND sustainab*)
(life cycle analysis AND sustainability production)
livable cities OR livable city
low carbon economy
medium and small entrepreneur
metropolitan planning organization
(microenterprise AND (sustainab* OR development))
(microfinance AND sustainab*)
(middle income group AND sustainab*)
mobile source pollutant
percent GDP to research
(public health AND resilient cities)
(public health AND resilient city)
(public infrastructure AND maintenance)
(public infrastructure AND sustainab*)
resilient cities OR resilient city
resilient infrastructure
resource footprint
(road transport AND sustainab*)
rural drinking water supply
(safety AND (transportation OR road AND sustainab*))
(sanitation AND (sustainab* OR development))
(sewer AND sustainab*)
(smart AND micro grid)
smart village
(social justice AND sustainab*)
solid waste segregation
structural equity
sustainability index
sustainable cities OR sustainable city
(technology AND resilient cities)
(technology AND resilient city)
(transport cost AND sustainab*)
(transportation cost AND sustainab*)
(urban AND water security)
urban drinking water supply
urban energy management
urban food security
(urban growth AND sustainab*)
(urban planning AND sustainab*)
urban waste management
urban water management
(waste water treatment AND sustain*)
(water conservation AND urban area*)
water footprint
water infrastructure
water resources development

THEME PLANET

The publications need to contain at least one of the keywords or combinations of keywords in abstract, title or keywords:

(adaptation AND climate)
(adaptive management AND climate)
AFOLU
Anthropocene
aquatic ecology
atmosphere-ocean coupling
atmospheric general circulation model
biochemical cycle
(biodiversity AND climate)
(bioeconomy AND climate)
(biological production AND climate)
carbon capture
carbon capture and storage
carbon cycle
carbon emission
carbon tax
carbon trading
clean development mechanism
climate change adaptation
climate effect
climate feedback
climate forcing
climate impact
climate mitigation
climate model
climate modelling
climate policy
climate prediction
climate service
climate signal
climate tipping point
climate variation
(conservation AND climate)
deforestation
desertification
Earth System Model
ecological resilience
ecosystem service
El Nino-Southern Oscillation
emission reduction
emissions trading
energy transformation
energy transition
(extreme event AND climate)
(financing adaptation AND climate)
(food chain composition AND climate)
glacier dynamics
glacier mass balance
glacier retreat
Global Circulation Model
global climate
global warming
greenhouse effect
greenhouse gas
greenhouse gases
ice-ocean interaction
Intergovernmental Panel on Climate Change
(island AND climate)
(land use change AND climate)
LULUCF
(megacities AND climate)
(megacity AND climate)
(mitigation AND climate))
(mitigation pathway AND climate)
nitrogen cycle
North Atlantic Oscillation
ocean acidification
ocean ecology
ocean temperature
Paleoclimate
radiative forcing
rain forest loss
rain forest restoration
reforestation
regional climate
sea ice
sea level pressure
sea level rise
submarine geophysics
(sustainable consumption AND climate)
sustainable fishery
(sustainable food production AND climate)
terrestrial ecosystem
thermal expansion
UNFCCC mechanism
United Nations Framework Convention on Climate Change
urban climate
vulnerability to climate change
weather extreme

THEME JUSTICE

The publications need to satisfy the following two conditions:

1. Contain at least one of the keywords:

actual innocence
armed conflict
civil conflict
civil war
conflict management
corruption
criminal law
democracy
democratization
ethnic conflict
exoneration
genocide
homicide
justice
miscarriage of justice
peace process
refugee
terrorism
violence

2. Belong to one of the following Scopus subject areas: social sciences, arts & humanities, economics, econometrics & finance, and multidisciplinary.

THEME PARTNERSHIP

The publications need to contain "sustainab" and at least one of the keywords or combinations of keywords in abstract, title or keywords:

Agenda 21
aid effectiveness
bilateral donor
capacity building
community-based approach
corporate social responsibility
global collaboration
global environmental governance
global framework
global governance
international agreement
international aid
international collaboration
international cooperation
international framework
multidisciplinary approach
multidisciplinary collaboration
multilateral institution
multi-sectorial approach
multi-sectorial collaboration
participatory approach
partnership approach
public private partnership
public-private partnership
(government AND (academia OR university OR industry) AND collaboration)
(government AND (academia OR university OR industry) AND partnership)
((university OR academia) AND industry collaboration))
((university OR academia) AND industry partnership))
((ODA OR power asymmetry OR accountability OR multi-stakeholder OR multi-level OR policy space OR policy coherence) AND (partnership OR collaboration OR cooperation))

Appendix E
Scopus Subject Areas Covered by Sustainability Science

Sustainability science is a broad research field that covers many different subject areas. In this appendix, we investigate the different subject areas in which articles in sustainability science are published. Our results show that the publications cover all 27 Scopus subject areas.[82]

In Figure A.1, we present the top 10 Scopus subject areas to which the publications in each theme belong. The top subject areas for the theme *Dignity* are social sciences and economics, econometrics & finance, contributing to the research about poverty and inequality.[83] The research on food security and agricultural systems are likely to fall under environmental science and agricultural & biological sciences.

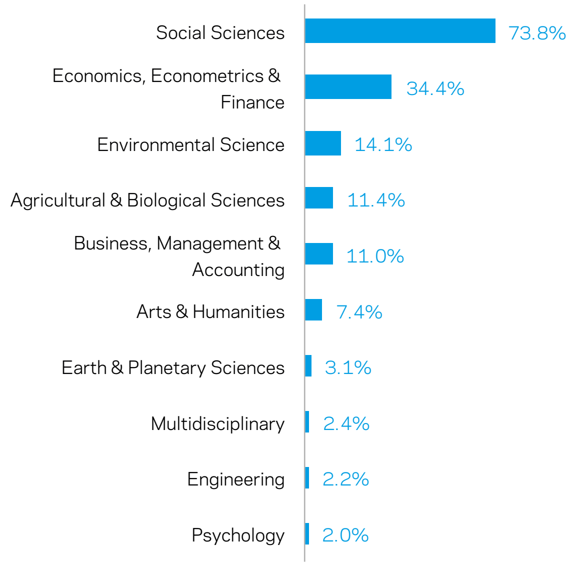
Medicine is unsurprisingly the largest subject area for the theme *People*, because one of the SDGs covered in this theme is about improving people's health. We also see that medical-related subject areas are among the top 10 for *People*. Other SDGs in this theme, such as education and gender inequality, are likely to fall under social sciences and psychology.

Prosperity is a very diverse theme, covering topics from water and energy to economic growth and infrastructure, and to cities and human settlements. This is reflected in the diverse Scopus subject areas it spans.

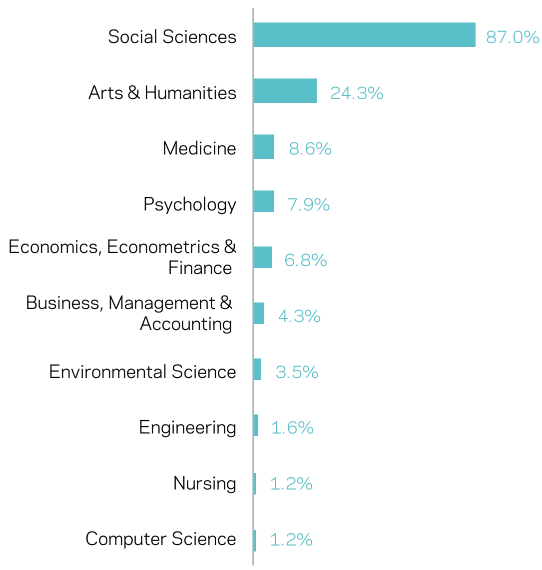
Planet concentrates on the subject areas in the domain of natural sciences. Environmental science and earth & planetary science have the highest share of publications in *Planet*.

In contrast, *Justice* concentrates on social sciences and arts & humanities.[84] Social sciences and environmental science are the two largest subject areas in *Partnership*.

Dignity



Justice



82 A list of the subject areas can be found in the title list of Scopus at *http://www.elsevier.com/_data/assets/excel_doc/0015/91122/title_list.xlsx*.

83 To search for the publications in *Dignity*, we made a selection of Scopus subject area (see Appendix D for the exact search conditions). In that sense the subject areas in Figure A.1 for *Dignity* are restricted by the search conditions. However, since one publication can belong to multiple Scopus subject areas, more subject areas appear on the chart for *Dignity*, even though they were not included in the original search.

84 Publications on law and justice belong to arts & humanities.

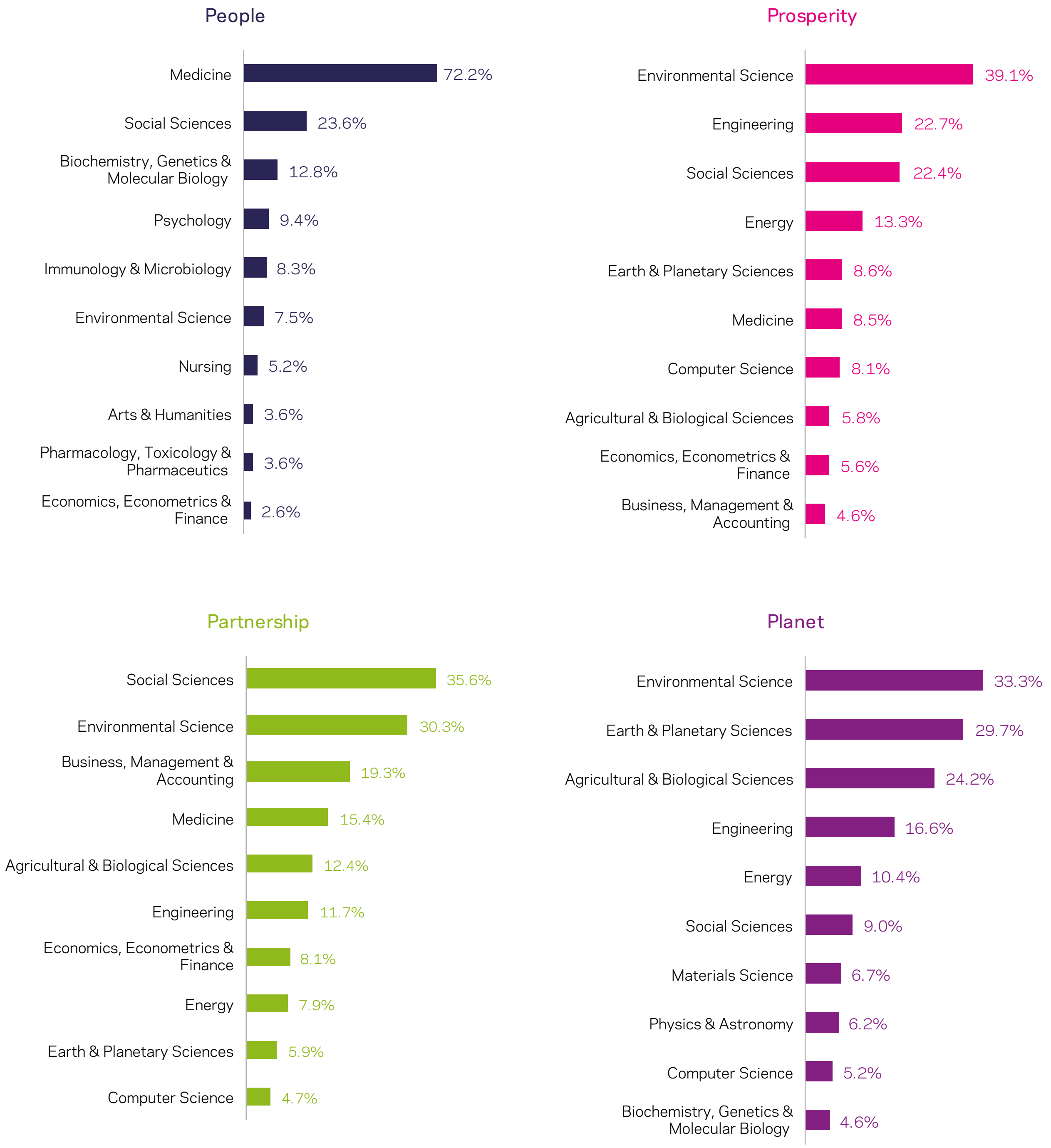


Figure A.1 — Top 10 Scopus subject areas; for the world; per theme for sustainability science; for the period 2009-2013. The numbers are the percentage of the publications in the subject area out of all of the publications in the theme.

About

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