RESEARCH FOR CHANGE

Towards a transformative research strategy for climate-resilient agriculture in Germany

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Towards a transformative research strategy for climate-resilient agriculture in Germany

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1. INTRODUCTION

At the end of April 2021, the German constitutional court ruled that the country's 2019 climate protection act is unconstitutional. By postponing high emission reductions until after 2030, the court argued, the climate law shifted the burden of ambitious greenhouse gas (GHG) reductions to future generations. In effect, the legislature must increase the level of ambition to respond to the court's ruling.

The agricultural sector is key to achieving such targets. In 2018, agriculture accounted for 7.4 percent of Germany's GHG emissions, and 63.6 million tons of CO2 equivalents (CO2-eq) in absolute terms (Umweltbundesamt, 2021). If emissions from agricultural use of soils are included, this share rises to 13.4 percent. Estimates from 2006 suggest that the share of the agriculture and food sector rises further to 25 - 33 percent when GHG emissions from the production, marketing, and preparation of food are taken into account (Grethe et al, 2021).

In terms of climate change mitigation, Germany has committed itself to reducing GHG emissions by between 80 and 95 percent by 2050, compared to 1990 levels. After the decision of the constitutional court, the revised reduction targets are even more ambitious: climate neutrality should now be reached by 2045. Using 1990 as its baseline, the country aims to realise an 88 percent reduction in its GHG emissions by 2040. By 2030, the German government stipulates a reduction target of 65 percent per sector.

Applying the year 1990 as a baseline, GHG emissions of the sector have decreased by 22 percent (KlimAgrar, 2020). However, most of these reductions can be attributed to the shrinking number of livestock in former Eastern Germany in the years immediately after unification. In fact, emissions by the sector stagnated, or even increased slightly in comparison to total GHG emissions in Germany (Umweltbundesamt, 2019). Further, carbon capture through land use, land use change and forestry (LULUCF) for agriculture has decreased since 1990 (Thünen Institute, 2018). According to 2020 estimates (Thünen Institute, 2020, 38), it is highly unlikely that the sector will achieve the required 15 percent of GHG reductions (about 10 million tons CO2-eq) by 2030 if current measures are continued.

The final version of the new climate law allows for annual emissions of 56 million tons of CO2-eq by 2030; which represents a lower reduction target for agriculture compared to other sectors. This acknowledges the specific challenges that agriculture faces in reducing GHG emissions. At the same time, the climate law establishes that the agricultural sector needs to contribute its share to meeting Germany's climate targets.

Germany faces a similarly challenging situation in terms of its climate change adaptation targets. In 2020, the agricultural sector experienced a third consecutive year of drought, with much lower than usual rains in the summer months. The shortfall was only partially compensated for in the respective winter months. Extraordinarily high summer temperatures in 2019 further led to increased evaporation and too little water content in topsoil layers. With dry conditions continuing in 2020, water loss affected the deeper soil layers (Umweltbundesamt, 2020), leading to reduced crop yields for the third year in a row in some regions. Moreover, the changing climatic conditions affected both arable land and grasslands, leading to a shortage of feed on many cattle farms. It is increasingly clear that Germany's agricultural sector will need to address climate change adaptation in the immediate future.

In considering these emerging climate challenges, the agricultural sector also needs to address its relationship to biodiversity loss, and other ecological crises. For example, the sector is a major contributor to elevated nitrate loads in water bodies, while the loss of soil organic matter further threatens biological diversity. If the agriculture sector continues to be an important driver of climate change, Germany will not only fail to achieve its climate targets, but also risks violating key European legislation, such as the EU Nitrate Directive, the EU Water Directive, and the EU Biodiversity Strategy 2030. In line with the European Green Deal and the Farm to Fork Strategy, it requires systemic approaches to the transformation of agricultural that address climate, biodiversity and water protection targets in an interrelated way.

Beyond these environmental linkages, the Covid-19 pandemic reveals the strong connections between public health, animal health, and the health of the planet. These different perspectives are brought together in the "One Health Approach," which promotes multi-sectoral responses to threats at the human-animal-ecosystem interface. The World Organisation for Animal Health estimates that 60 percent of all human infectious diseases are zoonotic in origin (2021). A 2016 report by the UN Environment Programme outlines how agriculture and related land-use changes, in combination with livestock production, constitute a key driver for the transmission of zoonotic diseases (UNEP, 2016).

Therefore, climate adaptation strategies for the agriculture sector need to start from an integrated land management perspective, with the aim of proactively realising synergies among these different dimensions.

Unfortunately, as indicated above, Germany's response remains ambivalent. One study concluded that the agricultural sector "is highly adaptable and resilient, historically responding to a myriad of factors including market prices, consumer demand as well as changing weather, where adaptation is the norm rather than the exception. But the sector was also found to be very resistant to change, constrained by tradition, support policies, and social and behavioural factors, constraining responses to major changes in paradigm" (OECD, 2017).

A key reason for this continuing policy inertia is the influence of diverse lobby groups, who seem to perceive an ambitious climate agenda as a threat rather than an opportunity (NABU, 2019). They include sections of the farming community and food industry, as well as their representative organisations. Such opposition not only leads to potential win-win solutions being left unexplored, but also weakens political responses so that they fall short of driving transformative change. Germany therefore continues to fail to establish a robust sector-wide strategy for climate change mitigation and adaptation.

Yet the overwhelming scientific evidence, as well as German public opinion, are united in calling for a differently constituted agricultural sector (Heinrich Böll Stiftung, 2019). Already in 2016, the Ministry for Agriculture's scientific advisory boards on Forest Policy and on Agricultural Policy, Food and Consumer Health Protection, outlined the most important areas for climate change mitigation by the agriculture and forestry sectors, and called for urgent action (Wissenschaftlicher Beirat Agrarpolitik, Ernährung und gesundheitlicher Verbraucherschutz and Wissenschaftlicher Beirat Waldpolitik beim BMEL, 2016). Numerous small-scale initiatives further demonstrate that change towards sustainability within the agricultural sector is possible. The lack of action cannot be blamed on a lack of knowledge.

Achieving transformation entails a political process of negotiation between different interests and objectives. Ambitious reforms will not take place without political will. Given the sector's longstanding orientation towards the single goal of "increasing productivity," it is challenging to shift gear towards a more systemic approach that links future ecological, economic and social goals into an integrated approach for resilient landscapes.

Science has the potential to support this transformation process. This paper proposes elements of a national research strategy for a transformation of the agricultural sector towards climate resilience.

We use the term climate resilience to highlight the need for ambitious, and integrated, climate mitigation and adaptation strategies that can support Germany in achieving its GHG pledges while respecting the interconnectedness of diverse ecological crises, as well as the multifunctionality of the agricultural sector.

Currently, there is neither a comprehensive research agenda for agricultural transformation towards climate resilience, nor the much-needed debate on the role of agricultural science within the transformation process. Technical knowledge on mitigation and adaptation policies exists. Technical innovations – especially driven by digitalisation of the sector – even play an important role in national innovation strategies. However, the more fundamental question of how we get to a climate-resilient agriculture and food system is not at the centre of agricultural research.

This question is of particular importance given the current imperative to build forward better from the Covid-19 crisis. Economic recovery programmes offer the opportunity to invest in agricultural innovations. As an overarching multi-sector strategy, the European Green Deal provides the roadmap towards that end. It would be a lost opportunity, therefore, if Germany's pandemic response did not support a more comprehensive shift towards climate resilience. To prepare for this shift, a systematic debate is needed to explore the kinds of innovations required to transform the agricultural sector towards climate resilience and sustainable development in general.

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2. DESIGNING RESEARCH FOR CLIMATE-RESILIENT AGRICULTURE

Knowledge and science matter in transformation processes. Knowledge can be used to accelerate such processes, but it can also be abused to halt or divert them. The way research is structured and financed; how problems are framed and research priorities set; how data is gathered and to whom it is accessible; all have a major impact on the answers provided by research.

As in other parts of the world, the past few years have witnessed a vibrant debate in Germany on the role of science in driving more sustainable pathways. Adopting the term "transformative research," proponents call for science that enables the necessary sustainability transformations. Working with stakeholders beyond science is a key component of this research approach. A recent position paper by the German Science Council (Wissenschaftsrat) situates the concept of practice (Anwendungsbezug) along the continuum of applied science (angewandte Forschung) and basic research (Grundlagenforschung). Its central tenet is to create the conditions that support the openness of science towards a broader cooperation with society. These conditions are surely not yet in place in all academic organisations. However, it is safe to conclude that there is broad support among academic audiences for exploring research approaches that offer practical guidance on how to transform Germany's agriculture and food sector towards climate resilience.

The focus of research in support of agricultural transformation should be to build knowledge for change, and direct this to support societal decision-making processes. This relates to both the farm level, as well as to national or supra-national policy making. Such research should build on the following four principles:

- **Be transparent about its normative basis, and the direction of the intended change:** Scientific research is not value neutral. Research that is (implicitly) affirmative of the status quo is not less normative than that which challenges this status quo. Hence, science that seeks to support the transformation of agriculture and the food sector needs to be transparent about its normative basis. This paper argues that global frameworks such as the Sustainable Development Goals and the Paris Climate Agreement, as well as EU-level agreements such as the European Green Deal and related targets for the sustainable use and protection of biodiversity and natural resources, provide the normative basis for the type of research being advocated here.

- **Focus on "how" questions:** There is a solid base of knowledge on the shifts required from the agriculture and food sector to contribute to the desired environmental outcomes. However, this knowledge often does not find its way into decision-making processes.

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Research in support of the necessary transformation of agriculture needs to focus on how to make this knowledge matter in decision-making. Through immersing themselves in the actual transformation process, rather than taking a more detached academic approach, researchers are more likely to identify the most relevant gaps to focus on.

- **Support multi-stakeholder engagement**: A corollary to focusing on the how is attracting broader participation in the research process. However, such participation should not be confined to a discussion of the final results. Involving a broad spectrum of stakeholders right from the onset of the research project design helps enhance the relevance of the research questions, and hence the overall utility of the findings. The terms "co-design" and "co-development" are increasingly used to describe the desired relationship between researchers and those in charge of implementing the findings of research projects. There are two distinct lines of reasoning in support of co-design and co-development: enhancing ownership by the intended users; and strengthening democratic decision-making more broadly.

- **Relevance of findings is also defined outside the scientific realm:** The peer review process assesses the validity of arguments offered by scientific publications. In line with the previous discussion of multi-stakeholder engagement, this paper argues that additional review processes need to be in place to assess the relevance of research in view of their contribution to address prevailing sustainability challenges.

In view of these general considerations, some of the roles that science can assume in supporting transformative processes towards climate-resilient food system include:

- **Generating knowledge about the transformation process itself:** It is important to understand the factors that lead to, or discourage, institutional change in relation to political processes and policy making. Such knowledge might refer to barriers and incentives, or the political economy of the transformation process. Fazey et al. (2018) highlight, among other issues, the necessity of analysing institutions as "rules of the game," and the impact of power on institutional change and how this relates to social transformation processes.

- **Developing technical, social, and political innovations for climate-resilient agriculture:** The bulk of research on climate change adaptation and mitigation to date has focused on technical innovations. Far too little scientific research has examined institutional, social, and political innovations (Davidson, 2016). Developing, testing, and evaluating a broad suite of innovations is a core theme of research for sustainability transformations in agriculture.

- **Understanding the positive and negative spill over effects of climate-related measures on other societal goals:** In 2009, scientists from the Stockholm Resilience Centre introduced the concept of nine "planetary boundaries," which they defined as the outer limits on damage to the Earth's natural systems beyond which catastrophe becomes increasingly likely. At present, most efforts around environmental policy are directed towards reducing just one of these: GHG emissions (Williams, 2020). A better understanding is needed of how such policies impact on other parts of the environmental system, as well as other societal concerns.

- **Facilitating transformation processes in case of diverging interests among stakeholders:** While transformation processes are fundamentally political processes that require understanding and negotiating divergent positions and interests, science can contribute to moderating these processes. Agricultural research in Germany has, for example, played an important role in facilitating debates on animal welfare in livestock production. There is also a need to address the connection between knowledge and decision-making. Far too often, this is reduced to science communication which is – in view of the above – a highly truncated version of this connection.

To catalyse the necessary changes within agricultural research, this paper makes the case for a national research strategy on climate-resilient agriculture. To date, no process has been initiated for developing such a comprehensive research agenda. Nonetheless, such an approach would not need to start from scratch. It could build on the lessons learnt in designing a comprehensive animal husbandry research strategy by the German Agriculture Research Alliance (DAFA, 2012). This research strategy, titled 'Measurable improvement in livestock farming from the perspective of society' allows for the use of societally relevant indicators to evaluate research findings. In the same vein, a comprehensive climate research strategy for the agricultural sector would need to incorporate at least three elements: (i) an orientation towards socio-political objectives; (ii) concrete verifiable goals; and (iii) a process for regular reviews of research progress applying a diverse set of criteria, as alluded to above.

Embarking on such a strategy would also imply making changes to research design. Some of the implications relate to:

- **The duration of inter- and transdisciplinary research projects:** Putting the aforementioned principles into practice takes time. In order to deliver relevant results, it is likely that projects will require longer funding cycles than the usual three-year period.

- **How to address perceived risks:** Transdisciplinary research involves bringing together a range of different partners, approaches, designs or ideas that can help deliver new insights. This might involve economic risks for farmers and other stakeholders in the food system. To encourage the application of innovative approaches, therefore, it is important to consider mechanisms for risk sharing.

- **How to facilitate co-learning in broader research networks:** Research networks, at national, regional and international levels, should enable all participants to learn from each other. In the realm of climate research, researchers in the Global South often possess substantially more experience and knowledge on adaptation, while mitigation may be the priority in many countries of the Global North. Research partnerships should therefore be designed to allow for equitable knowledge exchange between these research communities. This also means that there is a need to explore new funding mechanisms that allow for the transfer of resources to partners outside Germany and Europe, which is still not foreseen in all funding windows.

- **How to support critical research in public-private research partnerships:** It is key that public universities are adequately resourced to conduct research that is independent of private funding. At the same time, private companies play an important role in agricultural research. Recent analyses of agricultural research funding highlight that some areas are significantly disfavoured in terms of funding. A prominent example is research in agroecology. Co-operation between universities and companies might further influence the allocation of research funding. Hence, such public-private research partnerships require on-going scrutiny.

- **Meta-analyses for knowledge exchange and the identification of new research priorities:** There is a universe of individual research programmes on climate resilience of the agricultural sector. These research programmes adopt different methodologies, their findings pertain to very different contexts. Meta-analyses of these findings are a key step to facilitate knowledge exchange in the scientific community and to identify new research priorities.

- **A focus on model regions:** Research funding might also target entire regions that are considered to be highly important for climate-relevant agricultural research. Recently, the German Advisory Council on Global Change called for integrated landscape approaches to help solve the trilemma of achieving food and nutrition security, climate change mitigation, and biodiversity protection. However, implementing landscape approaches has proven to be difficult in practice. Undertaking such work at regional scale, which is characterised by complex interactions, provides opportunities to apply alternative strategies for climate-resilient agriculture. Comparative regional studies hence serve to arrive at more generalised findings that can be adapted in other contexts.

3. TOWARDS A TRANSFORMATIVE RESEARCH STRATEGY: UNDERSTANDING TRANSFORMATION PROCESSES

German agricultural research has amassed a broad range of knowledge on both climate mitigation and adaptation strategies. However, little systematic research has been undertaken on either the barriers to the adoption of these strategies in an integrated way, or the factors which drive such adoption starting at the farm and landscape level, and scaling these to the national and higher levels. An OECD (2017) meta-analysis of 114 climate-related agricultural research papers shows that considerable efforts have been devoted to understanding and developing technologies and practices that can help the agricultural sector reduce its GHG emissions and adapt to the impacts of climate change. The review also shows that the uptake of these climate-friendly technologies and practices remains low, lagging substantially behind available technical knowledge.

To arrive at a comprehensive understanding of how change happens, there is a need to focus attention on the research process itself. If research is to support transformation, it needs to place greater emphasis on the question of "how do we get from point A to point B?" Science has generated detailed understandings of the impact of climate change on agriculture. Similarly, there are detailed descriptions of desirable futures. Yet, far too little research is dedicated to the agricultural transformation process itself. This holds true for every step of the transformation cycle, from understanding goals and objectives, to developing a vision and pathway, implementing adaptation actions, or applying systematic monitoring and evaluating, as well as learning from these processes.

This paper advances two complementary perspectives for closing this research gap: analyses of the political economy of change, and innovation theory. While these perspectives are obviously rooted in very different theoretical schools, we submit that it is precisely by blending them that a comprehensive understanding of the barriers to, and drivers of change becomes possible.

LEARNING FROM POLITICAL ECONOMY PERSPECTIVES

One key barrier to change is the lack of government policies setting out the right regulatory framework or economic incentives for transformation to a climatesound agriculture and food system. As alluded to above, agricultural research provides a wealth of evidence on regulations and policies that would support an effective transformation towards climate resilience. Again, as stated before, these proposals have so far not been implemented. Researching the political economy of transformation can help us better understand the drivers of action versus inaction, and propose a range of entry points to advance the necessary change processes.

Scientific analyses of political power and lobbying provide insights into how such pressure curtails political decision-making processes, and ultimately slows down change. Such analysis can be enriched with case studies from other European countries that are successfully implementing more ambitious climate policies for their agricultural sector.

DISTINGUISHING BETWEEN CLASSIC AND TRANSFORMATIVE AGRICULTURAL INNOVATION

Climate-resilient measures, policies and techniques can be understood as a particular form of innovation (OECD, 2017). Due to the uncertainties associated with the climate crisis and the systemic nature of its impact on agriculture, several different forms of innovation are necessary. Classic innovations in agriculture tend to generate immediate benefits for the adopter, for example by increasing yields. However, such technical improvements may not advance knowledge on climate-resilient agriculture. The benefits of mitigation and climate change adaptation measures often accrue in the medium, or even long-term, and are fraught with uncertainties.

Innovation theory identifies a set of variables that support or hinder the diffusion process. Barriers and drivers of climate-relevant innovations appear at every level of the value chain: at the farm level (depending on the individual perception of future climate risks by the farmer); at sector level (for example through the market differentiation – or lack thereof – of climate-friendly agricultural products); or at the national or international policy level (such as the role of subsidies and regulation in promoting or discouraging climate-sensitive production). Hence, a better understanding of the factors influencing adoption of innovations along the value chain allows for the development of targeted support measures.

Perception of risk is a particularly important barrier to innovation. Innovation theory highlights risks such as the loss of market share or social acceptance. Since change is linked to uncertainty, it follows that the long-term transformation of the agriculture sector will inevitably be accompanied by risks for all stakeholders and decision makers involved. Hence a better understanding of perceived risks in agricultural innovation, and options for reducing such risks, will aid the transformation process.

FACILITATING TRANSFORMATION PROCESSES

Transformation should be understood as a political process of negotiation between different interests and objectives. Within the transformation process, such negotiations may entail arriving at a better understanding of potential synergies as well as possible contradictions among such interests, as well as finding ways to arrive at consensus. While this is not the role of science, scientists can help to facilitate such negotiations in order to create a transparent and knowledge-based process towards transformation. In this context, providing clear information about future scenarios, including the possible impacts of different technological options, can help enhance the confidence of all stakeholders involved in opting for transformative pathways.
The German Commission on the Future of Animal Husbandry (Kompetenznetzwerk Nutztierhaltung) can serve as an example of how science can facilitate transformation processes. Given the high stakes involved, the commission was tasked with supporting the development of the Ministry of Agriculture's farm animal strategy, with scientists playing an important role in managing tensions among the stakeholders.

One way to contribute to a more constructive dialogue between conflicting parties is to create transparency about the long-term effects of alternative policy scenarios. Key stakeholders such as farmers' associations and the food industry need to arrive at a better understanding of how action on climate, compared to inaction, will impact their respective interests in the long run. Currently, some farmers' associations wield their political power to halt progressive climate policies, although this may ultimately be detrimental to members of these associations. Ensuring transparency about the long-term impacts of such political strategies is therefore of utmost importance in securing the support of key actors.

4. TOWARDS A TRANSFORMATIVE RESEARCH STRATEGY: EMERGING THEMES IN MITIGATION AND ADAPTATION

According to the 'Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection' (2016), actions by the sector need to live up to the report's ambitious climate action scenario to deliver the necessary emission reductions. This will require far reaching changes, including in the management of nitrogen, renaturation of peatlands, and development of more sustainable production and consumption of livestock products. Building on the theoretical analysis provided in the previous sections, this chapter proposes an initial set of elements of what could constitute a transformative research strategy for climate-resilient agriculture in Germany.

> **"Globally, the EU is the second-largest emitter of greenhouse gas emissions from peatlands drained under agriculture, with Germany being the highest emitting country."**

4.1 MITIGATION

4.1.1 RESTORATION OF PEATLANDS

Natural, water-saturated peatlands in Germany store around 1.2 billion tons of carbon and are the largest terrestrial carbon storage in the country (GMC, 2016). Dewatered peatlands, however, emit large amounts of CO2, as the peat rapidly decomposes in the presence of oxygen. Globally, the EU is the second-largest emitter of GHG emissions from peatlands drained under agriculture, with Germany being the highest emitting country. Peatland-related emissions represent about 35 percent of the total greenhouse gases from German agriculture, although drained peatlands only make up 7 percent of the agricultural area (GMC, 2019). It is therefore imperative to restore the 1 million ha peatlands that are currently under agricultural use. Scientists from the Greifswald Moor Centrum (GMC), one of the internationally leading research institutes on peatlands, have called for a restoration of 50,000 ha per year in Germany until 2050. Further, there is already a proposal for such a restoration strategy that also addresses the necessary changes in laws and policies (Stiftung Klimaschutz, 2021)

From a scientific perspective, there is widespread consensus on the importance and effectiveness of peatland restoration.

Technically, the most effective method to avoid GHG emissions and to make peatlands an effective carbon sink is to raise the water level near the surface. Yet, more research is needed in developing the right incentives to protect peatlands. Two research areas stand out in this regard: (i) further developing concepts for the alternative use of peatlands under permanently wet conditions (paludiculture); and (ii) developing effective policy and market measures for the protection of peatlands, including the demarcation of peatlands as nature reserves.

There is low acceptance for a total halt of agricultural activities on peatlands. The question therefore arises as to whether peatlands could be used differently, under continuously wet conditions. The term paludiculture describes these new economic options of peatland use. Paludiculture encompasses new and applied concepts for value chains for wetlands. Rather than tinkering with crop rotations or optimising management, the use of peatlands is completely re-envisioned and redeveloped. Several research projects have already shown the suitability of paludiculture in different parts of the world. Relevant research questions on paludiculture go beyond land management. For cultivation under permanently wet conditions, new crops and machinery are needed, as well as new markets and value chains. It is also necessary to set up demonstration plots and experimental areas for applied research, training, and outreach.

Another research gap relates to how to provide incentives to set aside peatlands. Since this is primarily an economic question, costs must be calculated to set attractive prices for farmers to opt for the renaturation option. Another option would be state acquisition of land for the purpose of environmental protection. Science can help in developing and testing new finance mechanisms for the restoration of peatlands that account for the fact that farming activities in certain regions are predominantly conducted on peatlands. These research questions must be addressed in co-operation between different disciplines within agricultural research, in an interdisciplinary manner and in close collaboration between specialists from relevant disciplines and practitioners on the ground.

This realignment of peatland use requires considerable public expenditure. The effects of using public resources must be documented and evaluated, while the sustainability of various alternatives also needs to be assessed. Science is required to provide the empirical basis for these strategic decisions. Economic assessments of the positive externalities of peatland protection can further substantiate land-use decisions and demonstrate the public benefits generated by peatland protection.

4.1.2 CHANGING CONSUMPTION AND PRODUCTION OF ANIMAL PROTEIN PRODUCTS

Livestock production and the consumption of livestock products are important sources of GHG emissions from the agriculture and food sector. Measurements of livestock sector GHG emissions also need to factor in the entire global value chain. For example, they need to include the GHG emissions of animal feed produced in other countries. In Germany, approximately three-quarters of total agricultural GHG emissions are related to animal husbandry (Hirschfeld et al, 2008).

To reduce GHG emissions in agriculture, it is imperative that both consumption and production of animal protein is reduced. It has been estimated that if livestock production and the consumption of animal protein were reduced to levels recommended by the German Society for Nutrition (Deutsche Gesellschaft für Ernährung), it would result in a reduction of 22 million tons in CO2-eq emissions per year. This discussion is linked to the earlier point on nitrogen emissions from production systems. The demand and supply aspects that drive the high consumption levels of animal proteins need to be addressed simultaneously.

CONSUMPTION

While the factors that drive livestock production are relatively well known, much more research is needed to obtain a more detailed understanding of consumption patterns, as well as key drivers for reduced consumption of animal protein. One specific area of research is the analysis of selected target groups. There has been a relatively positive response by German society to the need to reduce the consumption of animal protein, with only a small group of primarily male consumers reported to have drastically increased their meat consumption (Heinrich Böll Stiftung, 2018). Interdisciplinary research is critical in understanding such contradictory trends, given that meat consumption is embedded within complex economic, political, and cultural systems (Rust et al, 2020).

How can governments support “food environments” that encourage sustainable, healthy, and fair consumption patterns? Despite the climate mitigation potential, most governments have yet to set reduction targets for animal protein, let alone introduce strategies to shift towards more plant-based diets. By ignoring the importance of dietary shifts, such inaction by governments could be misconstrued as a signal to the public that these issues are unimportant (Chatham House, 2015). Consumers will not change their consumption patterns merely because they have better access to information on the link between climate and the production of milk and meat. There is broad scientific consensus that individual consumption decisions are strongly influenced by social norms as well as by external influences. Prices, special offers, advertisement and the entire “shopping environment” influence purchasing decisions more than basic knowledge on sustainability, animal welfare, and health implications of meat consumption.

Governments must also not ignore the fact that in the current market environment, dietary decisions are predominantly influenced by private companies. Reducing meat and milk consumption requires changing the commercial infrastructure that prioritises animal-based proteins. This includes both the conditions under which consumers make decisions, options provided by public catering, and how healthy and sustainable nutrition is promoted by schools and other educational institutions. Moreover, the political environment that guides the development, affordability, and availability of meat and dairy alternatives is important in changing consumption habits (Fesenfeld et al, 2020). It is instructive that while meat alternatives are allowed to carry the name of the product they substitute, the European Court of Justice has rejected a similar approach for plant-based alternatives for milk, cheese, yoghurt, and similar products (ECJ, 2017). According to Chatham House (2015), the state is the only actor with the necessary resources and capacities to promote healthy and sustainable diets.

Furthermore, there is a need for research into political instruments for reducing milk and meat consumption. In Germany, the reduced VAT rate applies to livestock products. What would be the effects of increasing the VAT rate to the regular level of 19 percent? Research is needed on the effects of taxes on milk and meat consumption as well as how to link this revenue to the transformation of the livestock sector.

Besides contributing to a better understanding of the role of the state in inducing more sustainable consumption choices, research can also enhance our knowledge of the factors that influence individual consumption decisions. Key concepts in this regard are the role of market-oriented tools such as “nudging” (positive incentives for behavioural change) and labelling, as well as the effects of higher taxes on milk and meat consumption. A better understanding of how supermarkets, public canteens or restaurants can nudge consumers towards a climate-friendly diet is essential.

PRODUCTION

In view of the above, the potential to reduce GHG emissions from agriculture is severely limited if the total number of livestock remains at current levels. Measurements of GHG emissions from livestock production must also account for the effects of land-use changes from producing the soy meal and soy cake used in animal feed. Further challenges of livestock production include, but are not limited to, biodiversity loss, low producer prices and animal welfare violations.

In Germany, there has been a slight societal shift towards eating less meat and placing a greater value on ecologically- and animal-friendly diets. Yet, production patterns have so far not followed this path. Germany's livestock sector continues to cater to a low-priced international market instead of building a strategy to deliver high quality products to respond to national demand. Consumers' demand for higher standards (in terms of animal welfare, biodiversity protection and climate) require high investments in new production systems, such as improved livestock enclosures or stalls. Current state measures are too incremental to ignite transformative change at the systems level.

The role of research in supporting more assertive government action could include demonstrating how producers can be remunerated for investing in animal welfare, as well as climate- and environmentally-friendly production and supply chains. Research is also needed to better understand how farmers can diversify and shift their production and farm-level investments to adjust to a shrinking market for meat and dairy products. Adapted solutions are likely to differ according to context, for example the location of the farm, or the production model in use. However, even though transferability might be limited, farmers need to understand their transformation options.

Other European countries like the Netherlands and Denmark are developing progressive ways to decrease their total livestock numbers. The Netherlands, for example, pays farmers for downsizing their stocks. Some countries have introduced taxes to spur more sustainable production, such as a nitrate fee, or additional taxes for animal fats. Further research is needed to better understand the impact of these policies and test their applicability to the German livestock sector.

Another avenue for research is exploring the compatibility of animal welfare and climate change mitigation approaches. Animal welfare is traditionally associated with giving animals greater access to outdoor areas. Relevant indicators to assess different livestock production systems are climate impact, animal welfare, nitrogen management and operating costs. More research is needed to understand the trade-offs between indoor, outdoor and mixed indoor-outdoor production systems. Close collaboration between scientists and livestock producers is critical for developing climate-friendly production systems, and evaluating the overall public goods emerging from these systems. Pilot projects continue to play a key role in identifying livestock production systems that are fit for the future.

Private investors are increasingly exploring opportunities in disruptive research and technologies to develop meat alternatives. These include vegetable or egg-based protein and cell-based meat. With the aim of scaling up these alternatives as soon as they are market ready, such privately funded research shows a strong positive effect of market alternatives in reducing GHG emissions (Heinrich Böll Stiftung, 2018).

There is a need to better understand how these innovations will change the structure of the livestock sector since research is primarily driven by big tech and meat companies. The distributional consequences require particular attention: How will the resulting market trends impact on farms and businesses in both the Global North and South? What are new opportunities for farms to participate in this new market?

4.1.3 REDUCING NITROGREN EMISSIONS IN AGRICULTURE: MIXED FARMING SYSTEM

Agriculture is responsible for around 80 percent of Germany's emissions of nitrous oxide (N2O), a GHG 296 times more potent than CO2. The main source of N2O emissions are emissions from agricultural soils (Umwelt Bundesamt, 2014). In 2018, 38.8 percent of Germany's GHG emissions in the agricultural sector stemmed from soils (Haenel et al, 2020), primarily due to the overuse of nitrogen mineral fertilisers. Nitrogen fertiliser application is associated with direct N2O emissions from the fertilised soil while indirect N2O emissions are linked to the discharge of reactive nitrogen compounds such as nitrate and ammonia, and during the production and transport of fertilisers (Osterburg et al, 2013). There is scientific consensus that a decrease in the use of synthetic and organic nitrogen fertilisers, as well as overall nitrogen management, are of critical importance for climate-friendly transformation of the agricultural sector.

Managing nitrogen in intensive systems will not be enough to sufficiently curb nitrogen emissions from agriculture. To effectively address nitrogen-related emissions, it is necessary to reintegrate livestock and crop production in mixed-farming systems, with crop rotation playing a central role. The integration of nitrogen fixing fodder crops (e.g., clover or alfalfa depending on the geographical region) is associated with strong positive effects on nitrogen and carbon fixation in the soil. Additional benefits are enhanced water retention, soil health, and biodiversity. These integrated approaches, such as ley farming, need to be better understood from both an economic and ecological perspective (Loges, 2020a, 2020b; Lorenz et al, 2019; Loza et al 2021); Reinsch et al, 2021).

Further research needs for the upscaling of integrated farming systems include:

- Identifying optimal rotation systems for different geographical and climate regions, taking into account economic aspects and benefits for soil health, water retention, biodiversity, and carbon sequestration. Knowledge needs to be developed not only on the rotation system itself, but also on plant diversity and the corresponding composition of seeds.

- Developing new and adapted breeds and grazing systems since most high-output breeds used in milk production are not adapted to low-input production systems.

- Exploring new models of cooperation to optimise synergies between crop and livestock production. Introducing more sustainable mixed farming systems also needs to take into account different ecosystem contexts. This means that such studies need to be complemented with research on diversification of both plants and livestock, as well as different marketing opportunities for the resulting products, especially at the local and (sub) regional levels.

This represents a fundamental shift in current livestock production patterns, as European milk and meat production systems are designed to deliver high output in minimal time. Such intensification, which includes the use of high protein feed mixtures, exacerbates negative climate and biodiversity impacts. While a fundamental shift to such integrated farming systems is key to reversing such trends, there is little systematic support for research into this type of integrated farming systems.

"Agriculture is responsible for around 80 percent of Germany's emissions of nitrous oxide, a greenhouse gas 296 times more potent than CO2."

4.2 ADAPTATION

Various simulation models project a higher frequency, duration, and strength of extreme climatic events, like heat and dry periods, hail, storms, or floods. Apart from changing the planting seasons, the climate crisis is contributing to accelerated soil and land degradation, as well as increasing stress on water, plants and animal health (Rahmann and Schumacher, 2011). The agricultural sector is highly vulnerable to these changing production conditions and is, thus far, ill-equipped to respond to these challenges. Yet, there is next to no debate on how the agricultural sector should respond to the systemic challenges posed by the climate crisis.

To a large extent, scientific research on climate adaptation still focuses on selected aspects of adaptation. For instance, in plant production, much hope is placed on the development of drought resistant varieties by new breeding technologies. Yet climate resilience requires a completely different, systemic approach. There is little value in studying the performance of individual plants without embedding them in broader (and changing) ecosystems. A systemic focus therefore explores drought tolerance rather than resistance. Yields are the result of a complex interaction between plant or animal varieties, environment, and on-farm management (KlimAgrar, 2021). Therefore, agricultural production systems as a whole need to become more climate resilient through a mix of factors, including plant and animal diversification, greater water conservation and soil management, including significantly improved nutrient cycles. In a word, the systemic challenges posed by the climwwate crisis require systemic responses (Weigelt et al, 2020).

A recent meta-analysis compares the adaptation potential of organic and conventional farming. Organic farming is found to be better adapted to weather extremes like heavy rain or drought because it depends on investments in soil health, which in turn increases the soil's capacity to retain water (Sanders and Heß, 2019).

According to targets set by the German government, 20 percent of all agricultural land should be farmed organically by 2030. In addition, the government has developed a strategic plan for the development of the organic sector that is underpinned by a comprehensive research strategy (DAFA, 2017). However, only 1.5 to 5 percent of the total agricultural research funds so far have been invested in the organic sector (Clausen, 2020). This is likely to be reflected in a failure to achieve the 20 percent target.

We identify two pertinent research areas for supporting improved adaptation to climate change through organic agriculture and agroecological approaches:

PLANT BREEDING FOR DIVERSITY

The dominant agricultural research paradigm is out of sync with the systemic nature of climate-related challenges. While conventional breeding emphasises uniformity, responding to a changing climate calls for a greater focus on plant diversity and resilience. Against this backdrop, current approaches to plant breeding, which are dominated by new breeding techniques like CRISPR gene editing, are far too monodirectional. R&D investments by German companies and organizations are primarily driven by Bayer and BASF, the two largest agro-chemical companies globally (Clausen, 2020). Just like sustainable production processes, research innovations also benefit from the cross-fertilisation of ideas. It is therefore important to explore ways to enlarge financing windows for alternative and participatory plant breeding to add to the pool of ideas on climate-friendly agricultural pathways.

To support diversity and resilience, evolutionary plant breeding is proposed as a promising avenue (Döring et al, 2011). In essence, evolutionary plant breeding exposes crop populations to high levels of genetic diversity, which triggers the forces of natural selection. Through a cycle of sowing seeds from the previous plant population, plants become adapted to the prevailing growing conditions. Thus, evolving crop populations have enhanced capability to adapt to the conditions under which they are grown. In comparison to the preoccupation with uniform and genetically stable cultivars in conventional breeding, more diverse plant populations are much better adapted to environmental fluctuations and novel stress factors. Hence, they are also likely to be more resilient in contexts where the direction and range of environmental changes significantly increase uncertainty in plant production. However, to ensure access to more diverse seed varieties, significant injection of public funding for evolutionary plant breeding is needed. Furthermore, tailoring new varieties to actual needs at the local level also requires close cooperation between farmers and scientists.

AGROFORESTRY

Agroforestry systems can improve soil fertility, water quality and quantity, maintain biodiversity, and positively influence the microclimate. They also improve the resilience of production systems to extreme climatic events. Agroforestry systems already play a critical role in policies and programmes of many so-called "developing countries." Despite this wealth of expertise, agroforestry is not yet established in German production systems. Hence, agricultural research programmes can derive valuable lessons from the Global South on how to strengthen the adaptation of German agriculture.

The increased incidence of drought in Germany further highlights the urgency of investing in agroforestry systems. This implies studying broader value chains, as the availability of marketing opportunities will be an important determining factor in the uptake of such (in the German context) innovative production systems. Further, research needs to gather climate, soil, biodiversity, and yield data in different production regions and for different agroforestry production systems. A comprehensive understanding of the positive externalities of agroforestry systems would provide guidance for investment decisions that address climate related risks in agriculture.

4.3 GETTING THE INCENTIVES RIGHT

Germany has committed itself to becoming fully climate neutral by 2045. Yet, Matthews (2020) makes the case that, under current trajectories, EU Member States should not expect to make further significant GHG reductions in agricultural emissions by 2030. Even if additional measures are implemented that are currently at the planning stage, agricultural emissions are expected to fall by less than five percent for the period between 2017 and 2030. During the preceding period (2005-2018), agriculture contributed just one percent of the emissions reduction, a mere 2 million tons CO2-eq of the total 309 million tons CO2-eq emission reductions. To deliver its contribution to GHG reduction, agriculture needs to significantly raise its level of ambition.

Enabling agriculture to step up its contribution to climate change mitigation will require the deployment of all the available tools and options for curbing GHG emissions and increasing the absorption of carbon from the atmosphere (Lóránt and Allen, 2019). It requires decisive action spanning both food production and consumption to transform agriculture towards climate resilience. To achieve the required systemic changes, current agricultural incentives need to change. In addition to the range of relevant national policies, there are two core instruments to achieve this at the European level: the Common Agricultural Policy (CAP) and the possible inclusion of agriculture in an Emissions Trading Scheme.

There is currently significant disagreement regarding the extent to which the current CAP Reform proposal lives up to the necessary climate ambition. The EU

Commission claims that 40 percent of the total CAP budget post-2020 will contribute towards achieving the EU target of reducing EU GHG emissions by 40 percent relative to 1990. However, the real contribution of the CAP to mitigation-related expenditures remains unclear, since it would largely depend on decisions by Member States, and the level of climate ambition of their respective national CAP Strategy Plans. The European Court of Auditors just concluded that the contribution by CAP payments attributed to climate action only had marginal impact on emissions reduction.

Scientists and civil society organisations (CSOs) across Europe criticise the CAP reform proposals for their lack of climate ambition. For example, the current plans still include the heavily criticised per-hectare payment scheme. Further, critics highlight major shortcomings such as the absence of binding climate-related targets or indicators, and the lack of a clearly quantified climate-related share of the agricultural budget.

Moreover, the current design of the CAP and its application in Germany undermines decisive climate action in at least two of the areas discussed above: (i) peatland management and (ii) agroforestry. An example of continuing perverse incentives in this regard is the fact that while drained peatlands are eligible for CAP payments, farmed wet peatlands are not. This is highly problematic for a CAP that promises to have climate as its central focus for its next implementation period beginning in 2023. Even though the establishment of agroforestry systems can be financed through the second pillar of the CAP, the German Laender did not include this option in their rural development plans (Ökolandbau, 2018). Furthermore, CAP subsidies do not apply to all potential agroforestry plants. They are restricted to either short rotation coppice based on fast-growing trees such as poplar or willow, or on trees and hedges registered as protected landscape elements pertaining to the cross-compliance requirements of good agricultural and environmental practice. Hence, the current provisions of the CAP might raise the opportunity costs for adopting agroforestry.

The European Court of Auditors evaluated the effectiveness of CAP payments for adaptation and mitigation of climate change. Analysing payments made in the period 2014 – 2020, the Court found little evidence of their effectiveness (European Court of Auditors 2021). There cannot be any doubt; the CAP needs further reform to allow for a climate-friendly transformation of the agricultural sector. In fact, the German Advisory Council on Global Change advises to develop the CAP further into a Common Ecosystem Policy (WGBU, 2020).

A range of key research questions arise that are of outmost importance for the future design of the CAP:

- How can science develop suitable monitoring mechanisms to track national and EU-wide biodiversity and climate targets (as well as their interconnectedness)?

- How can research contribute to more holistic perspectives on emissions reductions within the context of agriculture and food systems? Such perspectives include accounting for different greenhouse gases and the possibilities for reducing them, and how these relate to other social and environmental goals. In this context, further research is needed on a climate-resilient CAP architecture and the necessary elements of regulatory policy.

- How can we better assess the impact of different peatland production systems and how to integrate them in the CAP? The same holds true for a better integration of agroforestry systems in the CAP system.

In addition to proposed reforms to the CAP, efforts are underway to integrate agriculture into an Emissions Trading Scheme (ETS). Isermeyer et al. (2019) demonstrate that those sectors integrated in the ETS registered greater reductions in emissions compared to "non-ETS" sectors such as agriculture. According to the authors, the inclusion of agriculture into a pricing system for greenhouse gas emissions would have a range of advantages: (i) scarcity signals via prices for consumers and companies; (ii) allocation of reductions where they cause the lowest economic costs; and (iii) ensuring synergies with globally-coordinated climate mitigation policies. For practical reasons, they propose to link the ETS to specific "bottlenecks" of the agricultural system, such as fertiliser production units.

However, there are concerns regarding the integration of the agriculture sector in the ETS (WBGU, 2020; IATP, 2020). Some of the remaining research gaps include:

- How would the ETS affect carbon leakage effects and which measures could prevent them?
- How does the inclusion of agriculture in the ETS affect, or possibly conflict with, other public goods and targets such as land concentration, the protection of biodiversity or animal welfare?
- Under which conditions would the inclusion of the agriculture sector in the ETS lead to the necessary reduction of CO2 emissions and the systemic transformation of the agricultural sector within planetary boundaries and a One-Health-Concept?

"There cannot be any doubt; the Common Agricultural Policy needs further reform to allow for a climate-friendly transformation of the agricultural sector."

5. CONCLUSIONS

Considering the significant role that the agricultural sector plays in emitting GHG and exacerbating the climate crisis, we argue that current policies remain woefully out of sync with both scientific advancements and the bulk of public opinion in favour of more sustainable food production and consumption. So, what is the role of research in spurring the policy and behavioural shifts that are needed to deliver a sustainable, fair and climate-resilient future?

Consumers are increasingly putting their money where their mouth is by opting for more sustainable food choices. Yet, it would be a mistake, if research would focus on supporting this behavioural change alone. Important as they are, consumers choices alone are insufficient to change the design of the agricultural sector. The current state of agriculture and its climate impact is the result of agricultural policies that have directed agriculture into this very state. It is therefore key that agricultural research focuses on the necessary policy reform processes.

It is against this background that this paper argues for developing a comprehensive research agenda for climate resilient agriculture in Germany. As one of its key components, this research agenda should also focus on policy processes to support the necessary transformation towards climate resilience.

This research agenda relies on interdisciplinary science, practitioners and citizens, and decision makers as co-creators of knowledge. Mutual learning, co-creation and communication are important elements of this type of transformational scientific work. The results of this research would primarily be evaluated in view of its contribution to advancing the necessary transformation of agriculture towards achieving Germany's commitment towards the Paris Climate Agreement and the Sustainable Development Goals. In designing such a research agenda, there is no need not start from scratch. Co-creation of knowledge is, for example, deeply rooted in research on organic agriculture. Now, it is time to scale these experiences up.

Agricultural science, obviously, cannot push the agenda of a climate-friendly transformation of the agricultural sector alone. Researchers need to build alliances with other stakeholders to create the necessary levers for change. The type of science that is needed is an engaged science in support of transformation.

Every sector of the German economy is obliged to deliver its contribution to the necessary transformation towards climate resilience and sustainable development. To support the necessary transformation of the agricultural sector, it is high time to develop a comprehensive research agenda towards climate resilient agriculture in Germany.

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