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REVIEW

Climate change and the urgency to transform food systems

Monika Zurek[1]*, Aniek Hebinck[2], Odirilwe Selomane[3]

Without rapid changes to agriculture and food systems, the goals of the 2015 Paris Agreement on climate change will not be met. Food systems are one of the most important contributors to greenhouse gas (GHG) emissions, but they also need to be adapted to cope with climate change impacts. Although many options exist to reduce GHG emissions in the food system, efforts to develop implementable transformation pathways are hampered by a combination of structural challenges such as fragmented decision-making, vested interests, and power imbalances in the climate policy and food communities, all of which are compounded by a lack of joint vision. New processes and governance arrangements are urgently needed for dealing with potential trade-offs among mitigation options and their food security implications.

Climate change poses one of the greatest threats to human societies, demanding immediate and coordinated actions across all sectors (*1*). Food systems are one of the most important contributors to climate change (*2*) and could compromise efforts to achieve the 2015 Paris Agreement targets (*3*). At the same time, food systems themselves will also need to further adapt to climate change impacts. The latest Intergovernmental Panel on Climate Change report shows that climate change has already negatively affected food production across the world and contributed to malnutrition (*4*). Temperature rises beyond 1.5°C are expected to transform terrestrial land ecosystems and shift climate zones (*5*), pressuring food security and livelihoods by affecting the productivity of crops and livestock (*4*), and warming of the oceans will reduce the productivity of fisheries and aquaculture (*6*). Together with more extreme weather events and sea-level rise, this level of temperature increase will exacerbate inequities in food access as food prices increase (*7*).

Simultaneously, food systems are responsible for about one-third of global anthropogenic greenhouse gas (GHG) emissions (*2*), presenting a major challenge—but also opportunities—for climate change mitigation (*8*). There are three major pathways through which the food system contributes to GHG emissions that present entry points for transformative change. The first pathway is through crop and livestock production, including all of the activities required to ensure that raw products leave the farm. These activities generate GHG emissions mainly through the methane and nitrous oxide produced from enteric fermentation by domestic ruminants (cows, sheep, and goats) and their manure, synthetic fertilizer applications on crops, and methane production from flooded rice fields (*9, 10*). Together, crops and livestock systems currently contribute 10 to 14% of total GHG emissions, which could increase to 40% by 2050 under some scenarios (*7, 9*). The second major pathway is land-use change, which contributes to GHG emissions mainly through deforestation and destruction of peatlands for agricultural purposes. Agriculture-related land-use emissions are estimated to be between 5 and 14% of total emissions (*7, 9*). The third pathway is through food-related activities beyond the farm gate, ranging from food processing and transport to food consumption. Food system–related emissions beyond the farmgate are estimated to be between 5 and 10% of total emissions (*9*).

Coordinated and successful implementation of a "menu" of mitigation and adaptation options for agriculture and food systems on a global scale could reduce GHG emissions to a safe level and support transformation to sustainable food systems (*10*). Mitigation options in food systems are generally organized around four key areas: improvements in the management of crops and livestock, land-use change, and food value chains, as well as altering food consumption patterns and reducing food waste. Although agricultural activities and land-use change are leading to a higher proportion of food system emissions than post-farm-gate activities, consumer dietary choices are a substantial factor driving decisions made on the farm. That said, post-farm emissions, including those from the energy sources used in food processing, food transport, food storage, and cooking, have been rising substantially in recent years, requiring a rethink of mitigation strategies for the food sector (*11*). A look across the whole food system therefore becomes important for finding the biggest levers of change.

Designing a menu of mitigation (and adaptation) measures

Although mitigation and adaptation options are plentiful in the food system (*12*), their

[1]Food Systems Transformation Group, Environmental Change Institute, University of Oxford, Oxford, UK. [2]Dutch Research Institute for Transitions (DRIFT), Erasmus University Rotterdam, Rotterdam, Netherlands. [3]Centre for Sustainability Transitions, Stellenbosch University, Stellenbosch, South Africa.
***Corresponding author. Email: monika.zurek@eci.ox.ac.uk**

reinforcing local rights and delivering benefits for local people. However, more clarity is needed on how the concept of nature-based solutions can align with Indigenous and local values and worldviews and, in particular, to explain that such solutions should not represent a commodification of nature (*6*). Nature-based solutions need to be understood as ways of working with, and as part of, nature and framed to ensure that multiple values of nature are respected. For this, the nature-based solutions community could learn from the Intergovernmental Platform on Biodiversity and Ecosystem Services in its efforts to develop an inclusive framework for understanding how contributions from nature affect people both positively and negatively (*52*).

There is also consensus on the critical importance of ensuring that nature-based solutions support biodiversity by protecting, restoring, and connecting a wide range of native habitats across landscapes and seascapes and by monitoring ecological outcomes (which are rarely quantified at present). Guidelines could more effectively promote biodiversity by recommending the use of the natural climate solutions hierarchy that prioritizes protection of intact ecosystems (*34*), as well as approaches that allow ecosystems to reach their full potential with minimal intervention [i.e., through "proforestation" (*53*)]. Practitioners would also benefit from understanding impermanence risks and adopting adaptive approaches to restoration. Given that local climate and disturbance regimes are changing, in some locations it may be necessary to restore and manage ecosystems by using different species that are able to thrive under unfamiliar conditions, including through assisted migration (*54*).

Guidelines are also clear that nature-based solutions are not an alternative to keeping fossil fuels in the ground. The challenge is how to direct rapidly growing public- and private-sector finance (especially via booming voluntary carbon markets) toward high-integrity nature-based solutions projects that are well planned and do not delay decarbonization. Part of the solution is regulation that restricts investment in nature-based solutions–related offsets to those organizations with ambitious yet robust and verifiable action plans to rapidly phase out the use of fossil fuels. This includes meeting stringent criteria for companies to reduce emissions throughout their operations and supply chains to be in line with the Paris Agreement's 1.5°C increase limit before or in addition to investing in robust nature-based solutions—for example, by adhering to the plan of the Science Based Targets initiative (https://sciencebasedtargets.org/). To ensure compliance, nature-based solutions should be rigorously assessed and validated, by methods such as long-term monitoring of social and ecological impacts. Government policy that supports robust accountability and regulatory frameworks for nature-based solutions would be transformative (*2*).

Ensuring the long-term social and ecological integrity of nature-based solutions requires an improved evidence base, informed by scientific, practitioner, and local and Indigenous knowledge. There is an urgent need for enhanced understanding of where, when, how, and for whom nature-based solutions can support both mitigation and adaptation, especially in marine and nonforest ecosystems, low-income nations in general, and their cities in particular (*20*, *21*). This research needs to take a holistic approach, for example, by considering how nature-based solutions influence the multiple dimensions of adaptation, not just exposure to immediate climate change impacts, and by comparing the benefits and costs of nature-based solutions with hybrid and technological alternatives (Box 1).

More regional and national scenarios and sectoral models of nature-based solutions climate change mitigation potentials are urgently required. These must be firmly grounded in the local policy and socioeconomic and cultural context, with robust consideration of permanence and leakage risks, interactions between ecosystems, feasibility, and outcomes for biodiversity, local people, and the economy (*36*). Such models must also distinguish afforestation from reforestation (*47*–*49*). Integrating landscape-scale experiments with recent advances in multispectral remote sensing, large-scale ecological observation networks, disturbance ecology, and mechanistic vegetation modeling will improve quantification of risks to the stability of ecosystems (*11*). Such research would also support the development of high-quality metrics that capture the multidimensional nature of biodiversity as well as the social outcomes of interventions. This information will allow baselines to be established and effects of nature-based solutions to be mapped and monitored over time, which is critical to improving adaptive management. Meanwhile, new research indicates that participation in nature-based solutions can lead to more-sustainable lifestyle choices (*55*); the role of nature-based solutions in enabling system change is a rich area for future study.

Addressing these knowledge gaps involves genuine collaboration between social and natural scientists, as well as between the scientific community and those Indigenous peoples and local communities who have been working with nature, as part of nature, for millennia. Only through such inter- and transdisciplinary efforts will we be able to implement nature-based solutions in a way that accounts for their multiple values. Such efforts are urgently needed to channel growing private and public climate finance to the projects and people that need it most—and in a form that will build rather than compromise the health and resilience of the social-ecological systems involved.

Conclusion

Nature-based solutions can make an important contribution to reaching net-zero carbon emissions this century, but only if combined with other climate solutions, including substantial cuts in GHG emissions across all sectors of the economy. This statement is not an argument against scaling up nature-based solutions. Instead, it underscores the need to consider the many other well-evidenced benefits of nature-based solutions, especially their critical role supporting social and ecological adaptation to climate change. Achieving net-zero carbon emissions and transitioning to a nature-positive economy will also require systemic change in the way we behave as societies, shifting to a dominant worldview that is based on valuing quality of life and human well-being rather than material wealth—and connection with nature rather than its conquest. Signals such as the rise of climate and nature grassroots activism indicate that this shift is taking place. If carefully implemented to ensure that multiple values of the natural world are respected, nature-based solutions offer an opportunity to accelerate this transition while also slowing warming, building resilience, and protecting biodiversity.

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implementation remains fragmented and uncoordinated, risking trade-offs with other food system outcomes such as food security or livelihoods (*13*, *14*). Harnessing the climate change mitigation and adaptation potential in the food system will require a critical systems perspective (*15*) to understand the pros and cons of these options, as well as relations among the different actors that might affect the implementation of an intervention. This approach could also help us to see beyond mitigation and adaptation options that target agriculture, which until now has been a dominant focus in literature and practice (*8*), to better include other activities down the food chain. For this, the diverse and interrelated activities that make up the food chain, as well as the wider social-ecological context and driving forces within it, need to be considered (*15*). A food system approach (Fig. 1) can illuminate several intervention points along the chain by modifying the drivers of food system activities (*16*). For example, farm activities can either contribute to GHG emissions or sequester carbon, depending on production practices (*17*). Similarly, dietary choices at the household level could significantly influence meat-production-related emissions (*18*).

Transformation of food systems around the globe is urgent, not only because of their GHG emissions but also because they fall completely short in equitably distributing food and providing food and nutrition security (*19*), resulting in hunger, malnutrition, and overconsumption (*20*). In addition, their wider environmental footprint related to biodiversity loss, deforestation, soil degradation, and water pollution is a key driver of environmental degradation (*21*). As currently organized, the food system also falls short on providing equal economic opportunities to food system actors or social equity at large (*15*, *22*) (Fig. 1).

Here, we review key food system climate change mitigation options and take a systems perspective to explore interactions with the main food system outcomes. We then examine some of the key stumbling blocks to achieving the necessary mitigation efforts in food systems and point to new ideas for overcoming these to bring about tangible food system change with mitigation benefits.

Climate change mitigation options in food systems

Climate change mitigation strategies across the entire food system fall into four main categories. We review some of the most important options, which range from improvements to cropping systems, livestock production, and supply chain activities to changing demand for products high in GHG emissions (Table 1). Although all of these options have GHG emission reduction benefits, they also have implications for other food system outcomes by creating potential synergies and trade-offs. Table 1 presents a few examples of these interactions, which need to be analyzed in their specific contexts to assess their true benefits.

Fostering synergies can offer a multitude of co-benefits. For example, agroforestry practices have major benefits, not only for the environment by fixing nitrogen and enhancing soil carbon sequestration, but also for society by increasing crop productivity by enhancing soil nutrients and organic matter. However, the adoption of agroforestry practices is often complicated by obstacles specific to the farming system context. Managing the risk of an unsuccessful transition can be challenging when no economic fallback mechanisms are available or when different inputs or new knowledge to change practices is required.

Adoption of a mitigation measure can also be complicated by associated trade-offs with food system outcomes. For example, closing yield gaps (i.e., the difference between the potential yield for a particular crop under optimal conditions and average farmers' yields in a particular location) is important for climate mitigation through reduction of demand for new land. However, closing the yield gap requires resource inputs, such as water and fertilizer (*23*), which might not be locally available, and their use could have other, possibly negative environmental impacts (*24*). Similarly, strategies for reducing GHG emissions from enteric fermentation in ruminants, which produces methane and is the biggest contributor to food-related GHG emissions, for example by incorporating marine algae into cattle feed, has a large mitigation potential, but large-scale seaweed harvesting will likely result in negative effects on marine ecosystems and also reduce their carbon sequestration potential (*30*).

Although options for mitigating climate change in agriculture and the wider food system exist, it is still not clear how these can be combined to reduce GHG emissions sufficiently to meet the 2015 Paris Agreement. Wollenberg *et al.* (*41*) were the first to calculate a potential target for agricultural emissions reductions by 2030 so that the sector could feasibly aim for the 2°C goal of the Agreement. The authors then investigated whether this target could be reached using various currently available agricultural mitigation technologies (for examples, see Table 1) and concluded that they would only deliver 21 to 40% of the required reductions in GHG emissions. Far-reaching efforts to develop further transformational technological and policy options are essential if agriculture and food systems are to play a significant role in achieving the Paris Agreement goals.

Systemic challenges to reducing food-related emissions

Despite scientific validation of possible mitigation options and strategies for addressing climate change, society has collectively failed to implement options or to "bend the curve" toward lower emissions. Several systemic and power-related

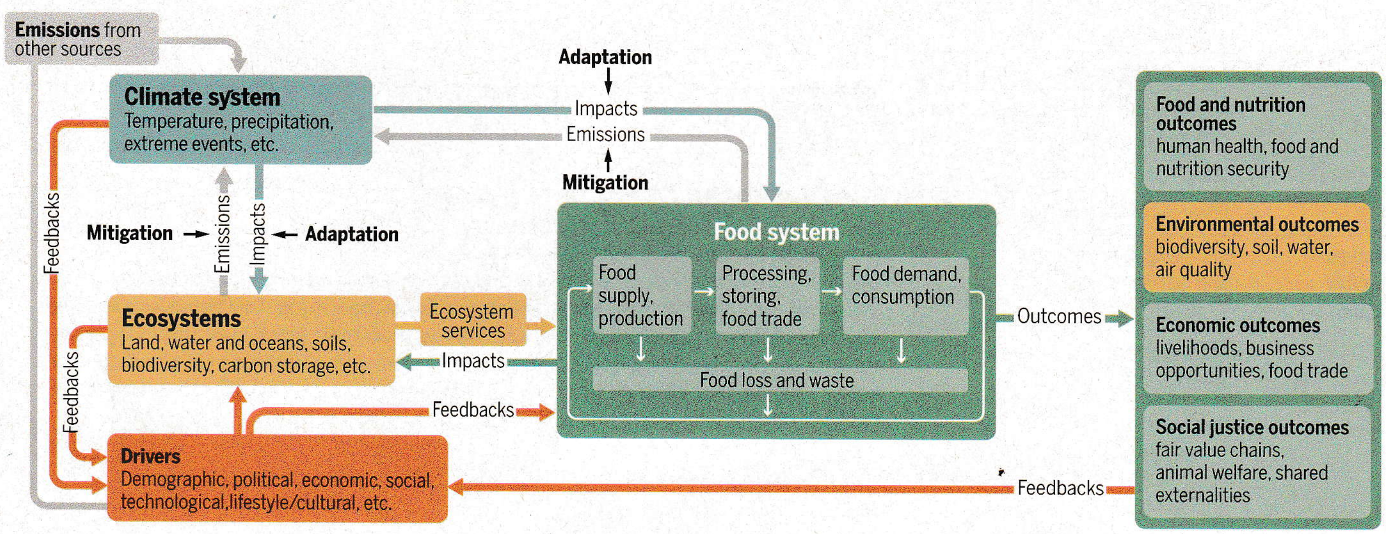

Fig. 1. How climate change, ecosystems, and food system drivers interact to affect food security [adapted from (*9*)].

Table 1. Climate change mitigation strategies across the food system.

MITIGATION AREAS	FOOD SYSTEM RESPONSES	EXAMPLES OF POTENTIAL INTERACTIONS WITH OTHER FOOD SYSTEM OUTCOMES (FOOD AND NUTRITION SECURITY, ECONOMIC, ENVIRONMENTAL, AND SOCIAL)
Improved crop management	Reducing nitrous oxide emissions from synthetic fertilizer applications	Synthetic fertilizer applications are important to current food systems, especially because manure and legumes can only provide a portion of total nitrogen demands of crop production. They have contributed to substantial gains in productivity of food crops and will continue to be important going forward, because demand for food is expected to increase. However, overapplication of fertilizer has led to major environmental impacts (*21*).
	Reducing methane emissions from paddy rice	Implementation of new agricultural management practices (e.g., alternative wetting and drying) by the many (small holder) farmers globally requires massive input from extension services (*25*), which brings uncertainties about the effectiveness of implementation.
	Improving land-use management for carbon sequestration (and reducing its losses)	The potential of carbon sequestration in agricultural lands is debated (e.g. issues with permanence), although it could be (with regional and local variations) considered a co-benefit of improving cropland and grazing land management (*26*). Restoration of peatlands and the reforestation of marginal and unimprovable agricultural lands should be a priority but conflicts with the increased demand for food (*27*).
	Closing yield gaps (differences between yields under optimal conditions and those attainable in farmers' fields)	Yield gap reduction has a substantial role to play in reducing the land needed for food. Improving yield gaps relies primarily on nutrients (fertilizer) and water management (*23*). In some areas, water required to close the yield gap might not be locally available (*24*). In terms of nutrients, some areas and regions of the world such as sub-Saharan Africa will need to increase their fertilizer use (*28*), and this will further increase GHG emissions. By contrast, many other parts of the world need to reduce fertilizer overapplication.
	Using agroforestry	Agroforestry is a land-sharing strategy that accommodates both agricultural production and biodiversity protection, resulting in improved nitrogen fixation, land and ecosystem health, and soil carbon sequestration, among other benefits. However, the implementation of this strategy depends on landowners and managers accepting and adopting these practices as well as various other socioeconomic barriers. Agroforestry suffers from similar challenges as conservation agriculture (*29*). To be successful, it will require investment to facilitate uptake in a way that is beneficial to landowners and managers.
Improved livestock management	Using better grazing land management	
	Improving manure management	
	Using higher-quality feed	There are various new options for reducing methane emissions by changing feeding practices for ruminants. For example, Roque *et al.* (*30*) suggested that introducing seaweed into the diets of cattle can reduce their methane emissions by up to 80% by changing the bacterial community composition in their guts. However, increasing the scale of seaweed harvesting would have large implications for marine ecosystems, including their carbon sequestration potential.
	Reducing enteric fermentation	Two main strategies for reducing enteric fermentation include feed additives and improving feed digestibility. Feed additives, while reducing GHG emissions from livestock, can leave toxic residues and have independent environmental impacts (*31*). Given the increasing risks from toxic residues and antibiotic and pesticide resistance, feed additives are not a clear way forward for mitigation (*32*).
	Reducing nitrous oxide through manure management	
	Sequestering carbon in pastures	
	Implementing best animal husbandry and management practices	
	Using nonanimal protein sources	
	Using microbial protein as feedstuff	
Improved supply chain	Improving food transport and distribution	Mitigation options here take two general forms. In low- and middle-income countries, where storage and processing facilities may be lacking, mitigation is geared toward reducing food loss through innovations and technology (e.g., cool storage options (*34*). In upper middle– and high-income countries, where use of technology and infrastructure is widespread, mitigation is geared toward improving energy use efficiency and transitioning toward renewable energy sources (*8*). A potential trade-off with the food system outcomes depends on the type of renewable energy sources used, e.g., the potential impacts of biofuels on food security is well documented (*35*).
	Improving efficiency and sustainability of food processing, retail, and agrifood industries	
	Improving energy efficiencies of agriculture	

Continued on next page

MITIGATION AREAS	FOOD SYSTEM RESPONSES	EXAMPLES OF POTENTIAL INTERACTIONS WITH OTHER FOOD SYSTEM OUTCOMES (FOOD AND NUTRITION SECURITY, ECONOMIC, ENVIRONMENTAL, AND SOCIAL)
	Reducing food loss	A large share of the food produced is never consumed. Reducing food loss would allow smaller yields to meet global food demand and also reduce emissions. Mitigation measures to address food loss often come in the form of innovations to improve the efficiency of food harvesting and processing. These innovations need to be both accessible and affordable to reach middle and smallholder farmers (*10, 34*).
Demand management	Making dietary changes toward sustainable consumption and healthy diets	Reduction in meat (especially beef and lamb) consumption is expected to have the biggest outcome for climate change and the environment (*9, 33*), especially as food demand, and especially for meat, is projected to increase. A growing number of upper- and middle-income consumers overconsume food, contributing to food demand, GHG emissions, and food waste (*33, 36*). Switching to healthy diets and following food guidelines has the potential to improve environmental sustainability and mitigation of climate change and also improve health outcomes (*37, 38*). However, healthy diets may be unaffordable and/or inaccessible to most of the world's poor and marginalized (*39*).
	Reducing food waste	The Food Waste Index report estimates that nearly a billion metric tons of food was wasted in 2019. More than 60% of this waste was due to household waste, with food service and retail contributing 26 and 13%, respectively (*40*). Reducing food waste has multiple co-benefits and provides synergistic outcomes for people by improving food security and regulating prices and for the planet by reducing pressure on land, biodiversity, and climate change.

issues, such as lack of coordinated climate action and vested interests in fossil fuel industries, are partially to blame, as are unbalanced power relations within food systems, which hinder progress in the adoption of mitigation strategies (*42, 43*). In addition to obstructing reduction of emissions, these issues have also exacerbated inequities between high- and middle- and low-income countries, because climate impacts have thus far mostly affected the latter (*20*). Stoddard *et al.* (*42*) set out the structural issues that have prevented any bending of the curve, and in this section we will also explore how these structural issues result in trade-offs between equity and climate change mitigation in food systems.

Addressing climate change is to a large extent a political matter that involves negotiations between governments and other stakeholders about how to coordinate action on a global scale (*44*). By coordinating and giving shape to climate action, the so-called "climate change regime" (*42, 45, 46*) has provided the dominant structure for such negotiations. It is this dominant governance arrangement that also decides about the allocation of responsibility for mitigation of climate change between states amidst north-south geopolitics (*44*). However, this is not an equal playing field, and concerns have been raised about how powerful countries have undue influence on the process. Furthermore, hindering coordinated action in this governance arrangement are the lack of binding targets for emissions, requirements for technology transfer, and funding for low-income countries (*42*). These issues directly influence food-related mitigation strategies in low- and middle-income countries that are the most vulnerable to climate impacts (*13*). In addition, the consensus-based decision-making approach might block the approval of mitigation options that benefit low- to middle-income countries but disadvantage high-income countries (*42*).

Although global climate governance has developed targets for the reduction of fossil fuel use and GHG emissions at a national level, wealthy countries nevertheless often outsource their environmental footprint and GHG emissions to other, poorer countries while also using land elsewhere for carbon offsetting at the expense of the people who live there (*47, 48*). In addition, vested interests from fossil fuel and dependent industries intervene on the decision-making processes at the national level (*42*), often pushing for nontransformative solutions that include technological optimism (*49*). Influence from such vested interests tends to lead to the adoption of the least disruptive changes, often leaning on future technological breakthroughs to ultimately justify business as usual (*49, 50*). Similarly, in the debate on the role of food systems in climate change mitigation, more narrow technological solutions have received much attention, often overlooking unintended or hidden social justice consequences (*51, 52*), for example, when innovative solutions are inaccessible to vulnerable food system actors, thus further widening the gap between rich and poor (*13*). In addition, the focus on tech-based solutions has sidelined the debate on the role of alternative, innovative solutions such as agro-ecology that are more locally based and scale appropriate for small-scale farmers (*50*).

The financial sector has also played an important role in shaping today's food economy by funding fossil fuel–reliant industries and business practices. Large-scale industrial agricultural practices are made possible by private sector finance and investments (*53*). By investing in responses and solutions that are preferred by the financial sector, financial actors have been influential in determining how climate risks are managed by the food system, for example, by proposing various carbon-trading mechanisms (*54*). However, because of the close relation between fossil fuel dependence and economic growth, a conflict arises between the feasibility of combining the current economic growth paradigm with the successful implementation of climate change mitigation options (*55*). Calls for more transformative and just climate governance require the "polluter elite" and transnational companies to take responsibility (*43*). In this scenario, financial capital institutions will have to develop and implement more innovative finance mechanisms to support transformative food system practices (*56*).

Although justice has been a core motivation for governing climate change at the global level, it is primarily understood in terms of equitable responsibility for or responses to climate change. This notion assumes that nation-states can protect and enforce climate justice, which overlooks multiple dimensions and narrows down action to north-south or developed-developing divides (*43*). This interpretation has obstructed the implementation of more transformative mitigation options. First, the focus on the nation-state has overlooked the role of private sector actors, such as the food industry, in climate mitigation. Whereas innovation of alternative and more sustainable practices and products is considered key for climate mitigation, decreased public spending has left their development primarily in the hands of private actors who often pursue for-profit aims rather than the common good (*13*). Second, much of the debate on climate mitigation is viewed from a global scale, disconnected from the local level and the consequences that mitigation measures might have on small communities and individuals (*57*, *58*). Not ignoring potential incompatibilities, even if a compromise could be found between globally defined mitigation options and locally oriented adaptation measures, these would be difficult to implement (*59*).

Interlocking decisions

Food systems, particularly agricultural production, are caught between the need to reduce GHG emissions and the need to adapt to new temperature regimes, precipitation patterns, and extreme future events. Policy and decision makers are faced with three interlocking decisions about mitigation of climate change in food systems: (i) available options in their specific contexts; (ii) how much GHG emission reduction can be achieved by each measure or a combination of measures; and (iii) how these options interact with food and nutrition security, the economic and social outcomes of the food system, and necessary climate adaptation measures. Table 1 shows examples of the connections between a range of mitigation options and food system outcomes. Reducing the amount of ruminant meat in diets, for example, has been discussed in many countries as the main avenue for consumers to contribute to GHG emission reductions. This can also help with the unwelcome negative health impacts of meat overconsumption but will affect livestock farmers' livelihoods directly by reducing demand and will also have implications for land-use and landscape management and, thus, biodiversity.

Navigating these questions will require evidence on the pros and cons for each mitigation option within a specific food system, and eventually decisions must be made that will very likely not please everyone. Because of the interconnected nature of food systems, these choices will bring with them unintended and unanticipated consequences, resulting in trade-offs for some actors within the system (e.g., reducing meat consumption will change livestock producers' income) and trade-offs between food system outcomes (e.g., environmental footprint versus income). Making these trade-offs more visible is important for finding ways to address them from the start. This is where a food system perspective is essential because it connects the activities of various stakeholders to food system outcomes. To change outcomes, activities need to change, incentivized by changing food system drivers (e.g., governance, institutional structures, tax regimes, and available science and technology options).

Reforming current structures and vested interests

How decisions are made and who makes them depends very much on the specific context of a food system and how it is governed. Many governments are now including agricultural mitigation options in their Nationally Determined Contributions to the Paris Agreement (NDCs), which are then meant to translate into concrete incentives for farmers and/or food industry actors to implement mitigation actions. What input these actors have when the decisions are taken depends on the institutional mechanisms available within their respective countries. Although many technical options are becoming available for both adaptation and mitigation in different food system contexts, it has not been straightforward to translate technologies into tangible changes on the ground. Even more difficult is balancing these options with the main task of providing food and nutrition security while also providing livelihoods and economic opportunities, managing wider ecosystem outcomes, and making food systems more equitable. This is where understanding vested interests on one side and the current structures governing climate change policy making and the entire food system becomes important, especially if we want a just transition of our economy and our food systems that includes vulnerable groups.

Although food systems differ greatly across the world in their components and contexts, we will nevertheless need to develop clear transformation pathways to achieve the Paris Agreement goals. How to decide on the right mixture of mitigation and adaptation options requires positive visions specifying what food system outcomes the actors want and what trade-offs they are willing to make. This requires negotiation between actors to provide coordinated innovation pathways and trade-off management. Several steps could achieve this. First, creating a map, ideally with the relevant stakeholders, of the particular food system with its dynamics, actors, activities, and outcomes helps to create a joint understanding of the process and boundaries involved [for an example of a food system map, see (*60*)]. Ideally this should include a set of compatible, integrated food system outcome metrics (*15*). The food system map should be made at the scale at which decisions on mitigation actions are taken (e.g., at a national level for the NDCs). A second step would be using participatory foresight methods, such as scenario planning or visioning, and the food system map so that food system scenarios can be built that explore the implications and trade-offs of possible mitigation and adaptation options. Here, it is particularly important to engage multiple stakeholders across the food system and include vulnerable groups and actors who might be negatively affected by possible changes. On the basis of the scenario analysis, coordinated, systemic mitigation pathways that include various options for change can be developed for the whole system. Tailored translation of mitigation pathways should be developed into actions for different food system actors, such as producers, value chain actors, consumers, or policy makers. This step needs to reduce or deal with trade-offs/unintended consequences. Evaluation and monitoring of outcomes based on selected food system metrics are needed to determine whether and how well the implemented mitigation pathways work. Finally, actions should be adjusted as needed based on the monitoring results.

Conclusions

We have the ability to develop options for mitigating climate change in agriculture and food systems. What is nevertheless difficult to achieve is deciding on the combination of options that need to work together in a specific food system to achieve the multiple goals that societies care about and to implement these in a consistent manner that is sensitive to local conditions. For this, we need to acknowledge and work with known power imbalances, vested interests, and fragmented policy making and monitor implementation of outcomes to be able to learn and adjust.

Food system change cannot wait, and neither can action on climate change mitigation, in which the food system has an ever more important part to play.

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