Feeding a net-zero world

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Feeding a net-zero world

Introduction

An affordable, secure supply of nutritious food is essential for food security and political stability in all countries. Maintaining this supply and ensuring its resilience in the face of climate change, increasing international tensions and trade frictions is imperative. Recent events have underscored the importance of this issue, with high food costs contributing to the cost-of-living crisis following Russia's invasion of Ukraine and the increasing number and severity of extreme weather events demonstrating the vulnerability of global food systems to climate change.

Food systems, which comprise the elements and activities related to producing and consuming food (including land use change), account for around one-third of all greenhouse gas emissions globally (IPCC, 2019[1]). Achieving the goals of the Paris Agreement and avoiding dangerous climate change will be impossible without their transformation. This includes drawing on agriculture's capacity to act as a carbon sink (through soil carbon sequestration) as well as finding low-emissions solutions along agri-food supply chains.

Food systems will need to adapt to climate change as well. Rising temperatures, more frequent and intense extreme weather events, and variations in rainfall patterns will have implications and pose challenges for how food is produced, transported and consumed.

Yet progress on lowering emissions from food systems, relative to other sectors, has been limited. Mitigation action will be needed in all sectors, including food systems, to reach global net-zero emissions. Agriculture has been so far largely exempted from legally binding targets and is often not integrated into national net-zero strategies. For instance, while most countries mention agriculture among sectors considered in their Nationally Determined Contributions under the Paris Agreement, only 16 of 54 countries surveyed by the OECD have any form of specific mitigation target for the agricultural sector (OECD, 2022[2]). The recent July 2023 UN Food Systems Stocktaking Moment (UNFSS+2) included a call to action to "align the implementation of national food systems transformation pathways with the continuous updates of National Determined Contributions (NDCs) and national adaptation plans (NAPs) for climate action."[1]

There is a strong case for a ramping up mitigation and adaptation ambition for agriculture, supported by concrete policy measures, including reforms to existing agricultural support policies. OECD data shows that support to agriculture (in the form of market distorting subsidies and trade barriers) remains high relative to other sectors and often increases GHG emissions, thereby working against national mitigation ambitions. Most common agricultural support measures, such as market price and commodity-specific support, inhibit the responsiveness of production systems, thus reducing incentives to adapting to a changing climate. Such policies also tend to distort international markets, which play a key role in attenuating the impacts of harvest shortfalls (OECD, forthcoming[3]). Agriculture is also a major consumer of fresh water globally and closely linked with global biodiversity loss, including through its effects on

[1] The 2023 UN *Secretary-General's Call to Action for accelerated Food Systems Transformation* specifies that this should include "...the adaptation of food systems to climate change and ecosystem service losses, and investments in building the resilience of agricultural systems and reducing the vulnerability of food producers who depend on these natural resources."
www.unfoodsystemshub.org/fs-stocktaking-moment/documentation/un-secretary-general-call-to-action/en

deforestation. Current agricultural policies may contribute to unsustainable water use, so reforms should take account of the need for incentives to prevent, and effective enforcement against, deforestation.

Much thinking is underway about what governments can do to drive the broader transformation needed to meet the "triple challenge" of food systems: improving the environmental sustainability of food systems; ensuring food security and nutrition for a growing global population; and sustaining livelihoods along the value chain. This will require new policy frameworks and investments to stimulate innovations that improve farming practices and technologies, and thereby promote sustainable productivity growth. Such frameworks should also include reforms to remove environmentally harmful support, policies to reduce food loss, and to shift the emissions intensity of consumers' food choices and reduce food waste.

Questions for discussion

The Round Table discussion will aim to directly address what is holding back progress on lowering food system emissions and what changes can accelerate it. Participants are asked to consider the following questions:

- Which innovations hold the greatest promise for deep long-term emission reductions while also addressing the 'triple challenge' faced by food systems?
- What is preventing faster progress on greenhouse gas emissions related to agriculture? What policy reforms and actions could overcome these barriers?
- What is the role of governments and industry in shifting behaviours and preferences, including on diets and on food wastage? What policies can contribute to this, and how can they be designed to gain social traction?

The triple challenge of food systems

Food systems are generally defined as all the elements and activities related to producing and consuming food, and their effects, including economic, health, and environmental outcomes. This includes agriculture but also processing, transport, storage, consumption and wastage of food.

From a government perspective[2], food systems pose a triple challenge: improving the environmental sustainability of food systems; ensuring food security and nutrition for a growing global population; and sustaining livelihoods along the value chain. These challenges present many synergies and trade-offs. For instance, higher food prices may help enable the adoption of more sustainable farming practices and raise farmer incomes, but may negatively impact food security. Certain new technologies can help increase farm productivity and income and may improve some environmental dimensions (e.g. by sparing land), but may potentially harm others (e.g. through more intensive use of chemical inputs). Nevertheless, with the right policy incentives in place, innovations can improve both productivity and environmental sustainability.

Addressing the triple challenge of food systems requires understanding the distributional implications of policies. Ambitious policy reforms in all sectors are likely to create winners and losers, and societal groups who benefit least from reforms may resist changes unless specific compensation mechanisms are in place. Meeting the triple challenge increases the complexity of reforms needed. Furthermore, food is often intimately connected to people’s values due to national culture, religious beliefs and self-image (e.g. food consumption choices signalling concern for the environment). It is important to take these aspects into account when assessing the implications of reforms.

Given these intertwined interests, the adoption of a “food systems approach” is needed to move forward with coherent and ambitious reform. A food systems approach opens the possibility of using different policy instruments to balance competing interests and values. This entails considering the impacts of all policies affecting food systems on farmer livelihoods, the environment and on food security, to foster synergies and avoid or mitigate unintended consequences. In other words, agricultural policies should be assessed for their impact on food security, livelihoods and the environment, and environmental policies for their impact on the environment, food security and nutrition, and livelihoods.

Divergence over facts, interests and values can often complicate and delay the introduction of sound food system policies. In many cases, evidence exists on how better policies can improve the performance of food systems, but important gaps in understanding remain. For example, if sufficiently granular data is lacking on environmental or socio-economic outcomes it will be difficult to study the impact of a change in parts of the food systems on these outcomes in detail. A key question to focus research and data collection efforts is which data and evidence are most important in reducing the uncertainty policy makers face (Deconinck, 2021[4]).

Impacts of food systems on climate change

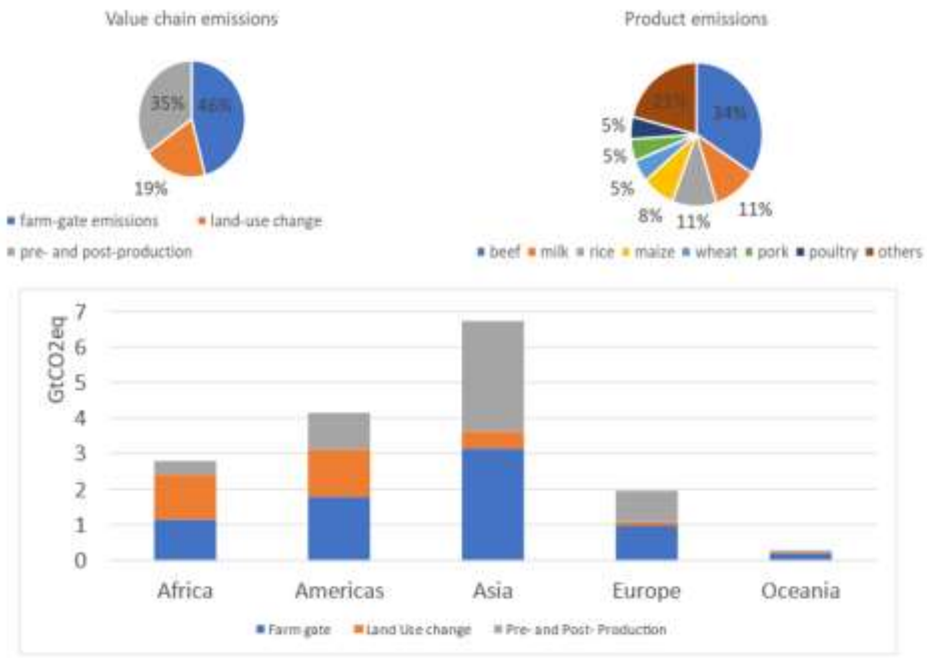
Food systems (including land use change) account for around a third of all global greenhouse gas emissions and should therefore constitute a critical pillar of net-zero strategies. While emissions from food systems have increased by 16% over 1990 levels (IPCC, 2022. See also Figure 3), significant mitigation

[2] This paper discusses the challenges and opportunities for aligning food systems to a net-zero world primarily in the context of OECD countries, so it may not fully reflect the contexts for developing countries.

opportunities exist. Moreover, agriculture has important potential for contributing to mitigation by sequestering carbon in biomass and soils. At the same time, food systems are highly vulnerable to climate impacts.

Greenhouse gas emissions are not evenly distributed across food system value chains. Agriculture and related land-use change make up about 65% of food-related emissions, with the remainder driven by both downstream (e.g. transport, processing, retail, packaging, waste) and upstream (fuel production) activities. Moreover, four agricultural products account for around 65% of emissions: beef, milk, rice and maize. If wheat, pork and poultry are added, the proportion rises to 80% (Figure 1).

Figure 1. Food system emissions by value-chain stage, product and region

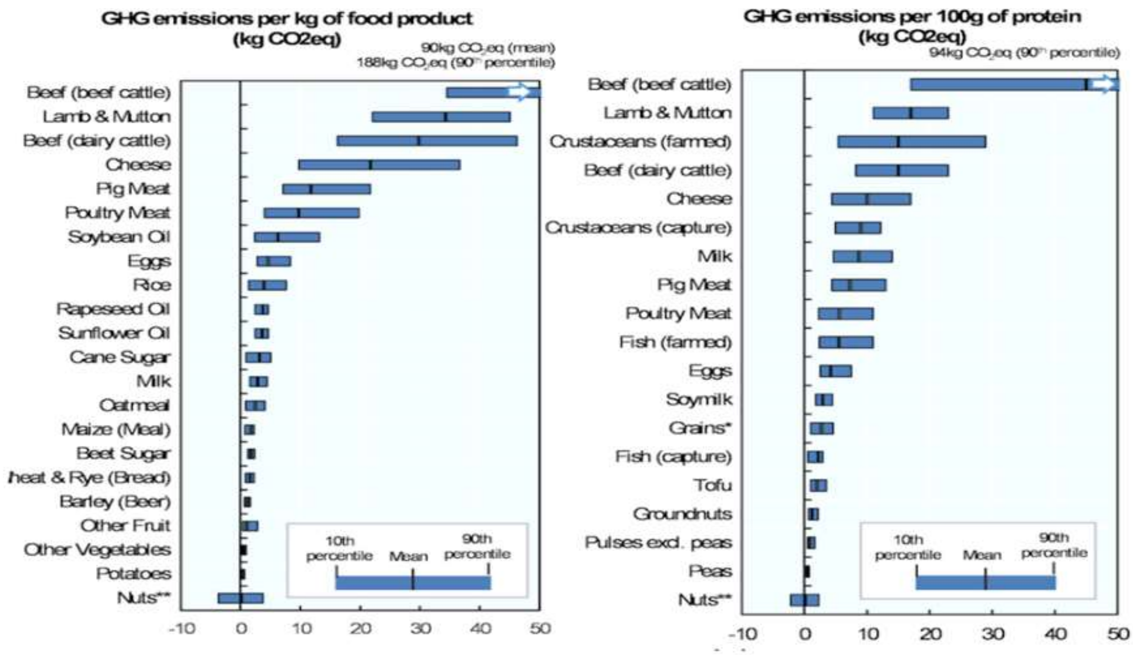


Note: Emissions are generated within the farm gate, by crop and livestock production activities; by land-use change, for instance deforestation and peatland drainage to make room for agriculture; and in pre- and post-production processes such as food manufacturing, retail, household consumption and food disposal.
Source: (FAO, 2022[5]), (Costa et al., 2022[6]), (FAO, 2022[5]).

As greenhouse gas emissions can vary significantly within a given foodstuff, average aggregated numbers can be misleading. For example, differences in productivity, diet composition and quality, and feed use efficiency can cause emissions from dairy beef production to vary by a factor of 12 (Poore and Nemecek, 2018[7]) (Figure 2). Furthermore, determining the precise carbon footprint of a particular food product is not straightforward due to a number of challenges relating to definition and measurement (Box 3).

Figure 2. Variations in emissions intensity within and between selected foodstuffs

Mean, 10th and 90th percentile emissions intensities (per kg of food product and per 100 g of protein)

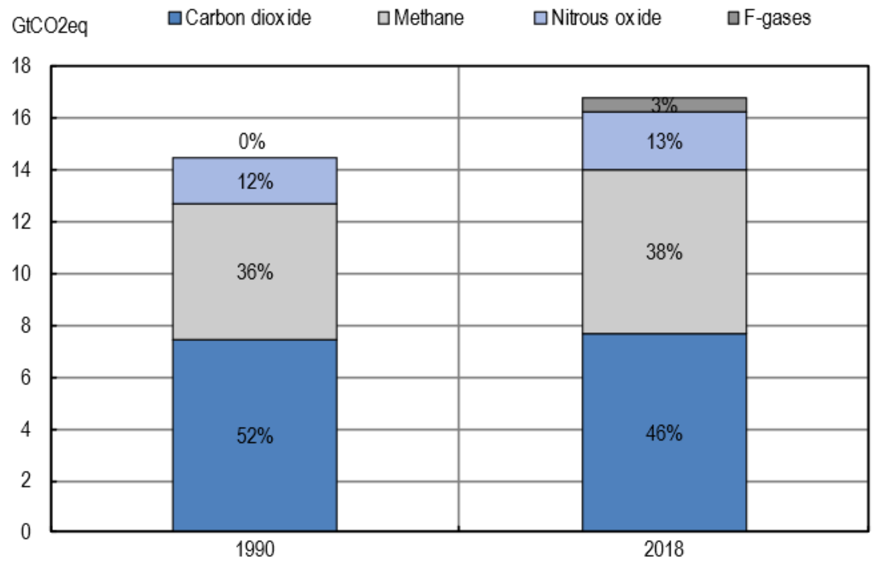


Source: (OECD, 2022[8]) building on (IPCC, 2022[9]), (Poore and Nemecek, 2018[7]).

While climate policies often focus on CO_2 emissions, nearly half of food system emissions are made up of other greenhouse gases, notably methane and nitrous oxide from livestock and crop production (Figure 3). Agriculture is a major contributor of methane and nitrous oxide globally, with on-farm emissions contributing 42% of total global methane emissions and 70% of nitrous oxide, the former mostly from enteric fermentation in livestock and from paddy rice production, and the latter largely due to animal manure and urine, and nitrogen-based fertilisers. Both gases have a much stronger effect on climate change per tonne than CO_2. Methane is a short-lived gas with higher impact in the short term, meaning that its effect on global temperature in the coming decades is substantially stronger than CO_2 (80.8 times stronger global warming potential (GWP) in "CO_2-equivalent terms" over a 20-year time frame, and 27.2 times stronger over the more commonly used 100-year reference period[3]). Actions targeting methane reduction are therefore a crucial element of food systems climate policies, with significant near-term impacts on lowering global warming. (OECD, 2022[8]).

[3] Estimates for the GWP of methane differ according to whether it is of fossil or biogenic origin. The values in this paragraph are based on the latter.

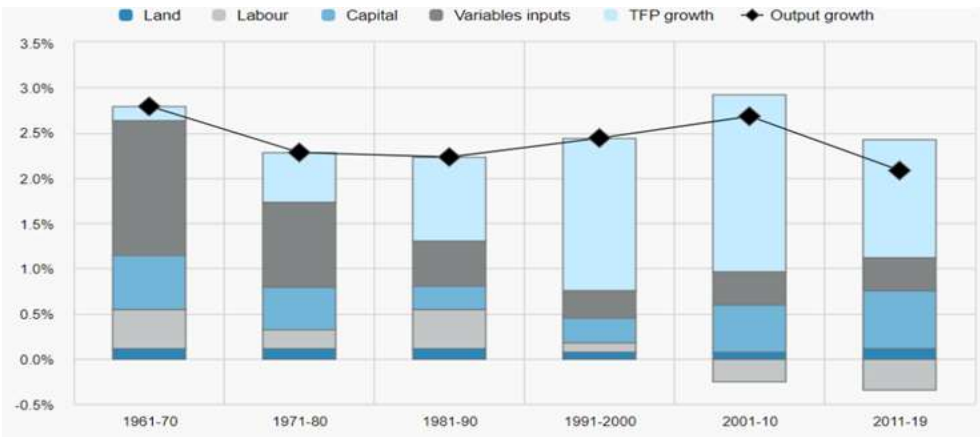
Figure 3. Global emissions from agri-food systems by gas in CO_2 eq



Source: IPPC, 2022 in (OECD, 2022[8]).

In recent decades, large productivity gains have helped to meet increasing global food demand while limiting environmental impacts. Production has increased using less land, supported through more efficient production systems, with increased total factor productivity growth associated with innovation (breeding, new technologies and improved management) (Figure 4). Since the 1990s, direct emissions from agriculture grew less than total production. For instance, between 1990 and 2016, direct GHG emissions from agriculture, global crop production and livestock production grew by 0.5%, 2.5% and 1.9% per year respectively (OECD, 2021[10]).

Figure 4. Sources of growth in global agricultural output, 1961-2019



Note: Each bar represents the annual average per cent growth over that period.
Source: (OECD, 2022[2]) based on USDA data.

Continued population growth, rising income in developing countries, and accompanying increasing demand for animal-based proteins are expected to sizeably increase emissions from food systems in the coming years. Without urgent action, food system emissions are expected to grow by about 30–40% by 2050 (IPCC, 2019[11]). This means that even if all other fossil-fuel emissions stopped now, emissions from food systems would be on course to use the remaining carbon budget for the 1.5°C and 2°C target (Clark et al., 2020[12]). Under a business-as-usual path, food systems productivity will need to increase by 28% by 2030 for the sector to meet both the Paris Agreement goals and the Zero Hunger SDG (OECD/FAO, 2022[13]). This is a significant challenge, given that the increase in global crop yields over the last decade has averaged 13% per year. Importantly, food systems also play a key role in meeting the objectives of the United Nations Kunming-Montreal Global Biodiversity Framework (GBF) (Box 1).

Box 1. Food systems and the Kunming-Montreal Global Biodiversity Framework

Food production is the most significant driver of terrestrial biodiversity loss (Dasgupta, 2021[14]). Meeting the objectives of the 2023 Kunming-Montreal Global Biodiversity Framework (GBF) will require important reforms in this sector.

Key actions identified by the Parties to the Convention that are relevant to food systems include:

- Ensuring effective conservation and management of at least 30% of the world's lands, inland waters, coastal areas and oceans.
- Ensuring that at least 30% of areas of degraded terrestrial, inland water, and marine and coastal ecosystems are under effective restoration.
- Reducing to near zero the loss of areas of high biodiversity importance.
- Halving global food waste and significantly reducing over consumption and waste generation.
- Reducing by half both excess nutrients and the overall risk posed by pesticides and highly hazardous chemicals.
- Progressively phasing out or reform by 2030 subsidies that harm biodiversity by at least USD 500 billion per year.

Source: authors.

Impacts of climate change on food systems

Agriculture is by its nature affected by climatic conditions, particularly rain-fed agriculture, and is therefore vulnerable to the impacts of climate change. These impacts are being increasingly felt today. Already in 2012, a historic drought in the US Midwest led to a 13% reduction in maize production compared to the previous year. This had global repercussions, as the US accounts for 40% of global maize production (USDA, 2013[15]). More recently, in 2022 Europe experienced its driest summer on record, leading to a drop in agricultural yields of up to 16% compared to previous years (Toreti et al., 2022[16]). Recent research from the Australian Department of Agriculture, Forestry and Fisheries suggests that changes in climate over the period 2000-2019 (relative to the period 1950-1999) have decreased average annual broadacre farm profits in that country by 22% (Hughes, 2019[17]).

Climate impacts can also affect food systems less directly. In 2019, increased intensity and frequency of cyclones in the Indian Ocean due to global warming created the perfect breeding conditions for desert locusts. Swarms of these insects destroyed crops across East Africa and left two million people with acute food insecurity. (IPCC, 2022[18]). In addition to extreme events, slow onset impacts are putting further stress on agriculture and food systems, with 250 million people globally affected by desertification (IPCC, 2019[19]), more than 13% of global soils affected by salinisation (FAO, 2021[20]) and almost 70% of OECD countries experiencing increasing drought (OECD, 2022[21]).

Climate shocks to agricultural yields or supply chain disruptions can lead to price spikes, limiting access to food. Increased climate variability can also lead to decreased nutrition through reduced yields of nutritious crops and decreasing the nutritional value of crops themselves, as well as causing considerable risks to food-system stability (IPCC, 2022[18])).

Climate-related risks to food systems can be amplified by food systems' own contributions to environmental pressures, for example through the aggravation of water shortages or lower soil fertility. This underscores the importance of emphasising agricultural practices that conserve biodiversity, enhance ecosystem services, improve soil health and water and air quality, and improve resilience to climate impacts while reducing agricultural contributions to GHG emissions.

Beyond agriculture, climate impacts are also being experienced in other parts of the food system. Trade and transportation are essential links in this chain: 20% of calories consumed globally have crossed at least one international border (OECD/FAO, 2021[22])). Climate shocks affect not only farming, but also transportation of farmed goods, for example if extreme events such as floods and landslides damage key transport infrastructure. Climate change will also impact labour productivity across food systems, for instance due to the effects of heat stress on workers.

Some climate change impacts are already "baked in" regardless of how successful future mitigation and net-zero policies may be. There is therefore a clear need to address food systems GHG emissions and food systems resilience simultaneously. Ensuring the resilience of food systems in the face of climate change requires broader economic resilience. For instance, as household income is an important determinant of food access, improving social safety nets will be instrumental in increasing food security and ability to adapt to climate shocks (OECD, 2023[23]).

Options for reducing emissions across food systems

The most recent estimates by the Intergovernmental Panel on Climate Change (IPCC) suggest that the agriculture, forestry and other land use (AFOLU) sector could contribute 20-30% of global mitigation efforts at relatively low cost (OECD, 2022[2]). Although the largest share of this comes from land use change in the form of protecting and restoring forests and other natural ecosystems, other aspects of food systems can play a significant role.

Concerted action to address food systems emissions requires a focus on both supply and demand (OECD, 2022[2]), which are discussed in the following sections with a focus on OECD countries. On the supply side, three areas of action stand out: first, reducing direct emissions from agricultural production and elsewhere along food systems value chains, including through enhancing productivity and efficiency of input use; second, reducing emissions from land-use change and enhancing carbon sequestration potential; and third, reducing food loss. On the demand side, shifting dietary preferences towards less emissions-intensive products and processes and reducing food waste is paramount.

A multitude of options exist for action across all these areas. A recent OECD survey suggests that citizens are open to interventions on both the supply and demand sides (OECD, 2023[24]) (Box 2). Venture capital investments are increasing for the development of alternative meats and proteins, which can be considered as an innovation that affects both supply and demand because of the need to develop new production process and new consumption habits. The double nature of this innovation is discussed in both the supply- and demand-side sections below.

Box 2. Household support for policies for greening food systems

The OECD Survey on Environmental Policies and Individual Behaviour Change (EPIC) builds on a sample of more than 17 000 households in nine countries.* Responses show strong support for policies educating school children about sustainable diets (78%), providing incentives for farmers to reduce environmentally harmful agricultural practices (74%), and stricter regulation of pesticide use, industrial animal farming and aquaculture (71%). Only 23% of respondents supported a tax on meat and seafood. Preferences did not vary much across the socio-economic characteristics considered in the analysis:

* Belgium, Canada, Israel, France, the Netherlands, Sweden, Switzerland, the United Kingdom and the United States.

Source: (OECD, 2023[24]).

Supply-side options

Aligning subsidies with climate objectives

Current subsidies and other forms of economic support are often not sufficiently aligned with climate objectives, and present a barrier to achieving these goals. Agriculture is a major recipient of public support worldwide, totalling USD 817 billion per year for the 54 countries covered by OECD data over 2019-21, of which USD 447 billion is from the public purse and the remainder passed on through higher prices (OECD, 2022[2]).

Two particular avenues stand out to reform or reorient subsidies towards more sustainable practices. One is to prioritise reforming support to the most emissions-intensive products and practices. For example, support to livestock amounted to 31% of total positive transfers to specific commodities in 2019-21, equivalent to a positive emissions subsidy of USD 22 per tonne of CO_2-eq for beef and USD 31 for sheep meat. Rice, which is emissions-intensive due to methane produced by flooded paddies, received support equivalent to USD 115 per tonne of CO_2-eq. This support should be removed, or if it is maintained could be made conditional on marked improvements on emissions intensity. Another effective avenue is to phase-out subsidies for harmful agricultural inputs, such as fertiliser, feed and fuel, in countries with significant overuse of such products. These forms of budgetary support could be reoriented from unconditional subsidies and instead used to fund low-emission solutions. More importantly, the pricing of agricultural emissions would be more effective at mitigating emissions (see section below on further research integration of food systems into economy-wide climate policies) because it places stronger incentives for restructuring the sector away from high- to lower-emissions commodities, and because many countries do not have significant levels of budgetary support to reallocate to low-emissions solutions. However, such ‘polluter pays’ policies pose important challenges associated with reduced net farm incomes and higher food prices.

Further, opportunities exist to improve land-based area payments to better align with a transition to low-emissions food systems, including through linking such payments to provision of environmental and ecosystem services such as carbon sequestration through afforestation or land rehabilitation.

Efforts to reorient subsidies are never easy. This is particularly the case for food-related subsidies in the current international context, given the tumultuous events of recent years. Measures need to consider potential impacts on food prices and producer incomes (OECD, 2022[2]).

Food prices have recently contributed considerably to the cost-of-living crisis and as a driver of inflation, due to supply disruptions and high prices following Russia's war against Ukraine, on top of rapid demand due to COVID-19 recovery spending and combined with climate-related disruptions to harvests in various parts of the world. Governments have implemented emergency policy measures to combat high prices and cost of living, both for energy and food, but support has not been sufficiently targeted, risking locking in energy-intensive and unsustainable consumption habits. A shift to targeted income support could provide considerable equity and efficiency gains, but requires detailed data on consumers and agricultural household income (OECD, 2022[2]).

In addition to efforts to combat emissions, there is also an urgent need for wider sectoral emphasis on promoting resilience. This will require changed practices at the farm level to do different things, or to do things differently, to reduce climate-related risk and enable faster recovery from climate-related events. It will also necessitate a re-think of how to insure farmers against climate risk: as severe climate events become more frequent it will be necessary to differentiate between business risks to be managed by farmers and catastrophic risks normally covered by taxpayers. Support programmes linked to wider social safety nets, for instance to assist farms that are no longer viable to exit the sector, will also need to be considered.

Innovation for sustainable productivity growth is key to reducing emissions

Direct on-farm emissions (mostly non-CO_2) result primarily from fertiliser use, irrigated rice, and enteric fermentation and manure management from livestock. Reducing these emissions will rely on a combination of improvements in productivity and efficiency of input use, improvements in farm management, and the deployment of new technologies. For example, estimates indicate that 45% of nitrogen added to fields globally is not absorbed by crops, implying considerable scope for efficiency gains. These can be achieved, for example, through precision agriculture and increased use of integrated crop management and rotation (e.g., with nitrogen-fixing legumes and cover crops) and crop-livestock integration (OECD, 2022[2]).

Rice irrigation is a major source of methane. Better water management practices such as midseason drainage or intermittent irrigation have been shown to considerably reduce methane emissions (OECD, 2022[2]). Further improvements include direct seeding of rice paddies and adoption of novel seed varieties (The Economist, 2023[25]).

New genetic technologies offer additional opportunities to advance crop resilience and productivity, and could play an important role in reducing food systems emissions (von Braun et al., 2021[26]). A shift from annual to perennial crops[4] would drastically cut emissions from agriculture and could significantly contribute to carbon sequestration and reduce erosion and nutrient leakage (Mirzabaev et al., 2021[27]). Some perennial versions of staple crops such as rice are already commercially available, with many others close to being so.

Viable options also exist for reducing livestock emissions. As most emissions come from enteric fermentation, herd genetics and feed and pasture quality are key (OECD, 2022[2])). Methane inhibitors,

4 Currently, 87% of crops globally are annually terminated and resown every year.

either chemically synthesised or through species-specific food supplements such as seaweed, as well as anti-methane vaccines, have all been heavily researched and could become commercially available (OECD, 2022[2])). Manure management through better storage and composting methods, including use of anaerobic digestors, could also limit CH_4 and N_2O emissions.

Advancing feed productivity and efficiency is increasingly important given competition between humans and livestock for crops such as soy and grain (Rivera-Ferre et al., 2021[28])). Examples here include the use of microbial protein produced from fermenting sewage and the use of super feeds such as algae or grasses (Herrero et al., 2021[29]). Use of novel technologies for livestock management such as virtual fencing and robotics could have further impacts (Herrero et al., 2021[29]).

Beyond targeting emissions from crop cultivation and livestock, on-farm solutions include the use of renewable energy sources and adopting greener and more efficient fuels to power machinery (OECD, 2022[2]). These solutions can be applied to other parts of food systems value chains, for example through reducing emissions from transport, processing and packaging. However, approaches to improving sustainability based on shortening supply chains (e.g. "zero-kilometre products") are likely to have limited climate benefits because of the small share of transport emissions in total GHG emissions from food systems. Impacts on other environmental dimensions and food systems goals such as food security and livelihoods depend on vulnerabilities and strengths in the exporting and local regions. The differing economic and employment importance of the sector across regions and countries needs to be taken into account.

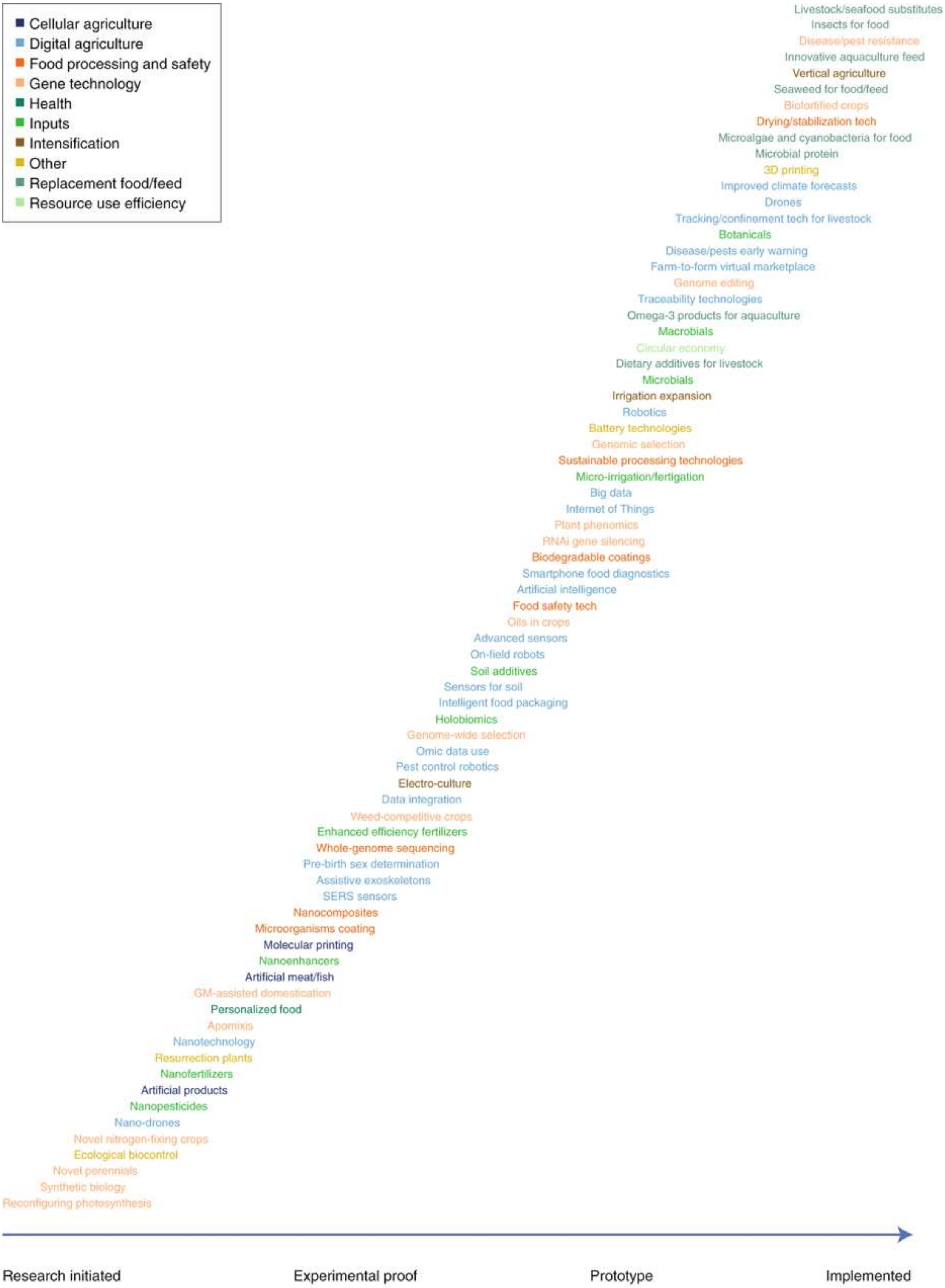
Digital technologies in agriculture can also help to increase efficiency in the use of inputs. The rapid technological improvement of remote sensing, drones and low-cost sensors – coupled with advances in data analysis allowed by artificial intelligence – can help to spot areas that need irrigation, fertilisation, protection from pests or other interventions. In addition to enabling technological developments on farms, internet connectivity enables access to digital services such as advisory services, financial services and e-commerce, all of which have the potential to enhance food system sustainability and resilience (Benfica et al., 2021[30]).

Finally, while the climate focus within food systems is primarily on soil-based agriculture, production of aquatic foods such as fish, shellfish and aquatic plants have shown considerable potential for reducing emissions and other environmental pressures, and should be better integrated into thinking on food systems (von Braun et al., 2021[26]). However, several factors (e.g. policy reforms, technological innovation) are needed to ensure that production increases potential are realised sustainably (Costello, 2020[31]).

Given the potentially large role of new technologies and practices highlighted above, agricultural policy reform should focus not only on supporting innovation but also on improving practices and systems. Currently, public investments in agricultural innovation remain marginal – equivalent to only 0.7% of the value of agricultural production in 2022 (OECD, 2022[2]). Policy attention is needed to improve existing practices where significant potential exists, as well as new technologies such as modified animal feed and alternative proteins. Figure 5 highlights the large number of new technologies relevant to food systems transformation and their highly different states of market-readiness, ranging from early research stages to full commercial readiness (Herrero et al., 2020[32]).

Finally, a significant issue in agricultural innovation is last-mile adoption: with farmers often older and less educated than the population at large, and concerned about the risks (including loss of markets) from new technologies and practices, ensuring the adoption of innovations remains an important policy challenge.

Figure 5. State of development of diverse food system technologies



Source: (Herrero et al., 2020[32]).

Innovation for alternatives to animal proteins

In addition to research to improve the efficiency and sustainability of food production, there is increasing interest in researching alternatives to animal proteins (Fasman, 2021[33]).

Alternative proteins, here defined as products that aim to mimic meat in terms of organoleptic (i.e. taste, appearance, texture) and nutritional properties, are attracting investment. Three main types of alternative proteins are usually identified: plant-based alternatives, which are plant-based products developed to taste like meat; lab-grown meat, which are products generated by animal cells (i.e. not resulting from the processing of live animals); and insect-based alternatives (both as sources of animal feed and human food). Importantly, hybrid products are also possible.

While implications of alternative proteins for the triple challenge vary according to each type and local context, broadly speaking these entail (Frezal, 2022[34]):

- **Food security**: Products tend to be more expensive and have a lower consumer acceptance, which limits their potential contribution to food security. However, as production scales up their prices will likely decline and consumer acceptance may increase.
- **Climate and environmental sustainability**: As livestock methane emissions account for almost half of the sector's GHG emissions, adoption of alternative proteins could substantially reduce emissions. Research shows that plant-based and insect-based alternatives have lower emissions intensities than meat. When the global average energy mix is considered, prospective life cycle assessments suggest that the emissions intensity of commercially scaled-up lab-grown meat products could be lower than beef, but higher than pork and poultry. However, if renewables were to become the dominant source of energy, the footprint of lab-grown meat becomes comparable to that of poultry (DELFT, 2023[35]). Regarding other environmental impacts, available evidence suggests that plant- and insect-based alternatives have lower per unit water requirements than all types of meats, while lab-grown meat only has lower requirements than beef.
- **Farmer livelihoods**: Growth in consumer acceptance of alternative proteins is likely to cause a decline in economic outcomes for workers in livestock supply chains. At the same time, it may create new livelihood opportunities in emerging alterative protein industries and avenues of diversification, especially at the processing and distribution stages of the value chain. Further research is needed, however, on whether new job opportunities would match the skills of negatively affected workers and would be created in the same regions where job losses take place.

Countries are progressively introducing frameworks to regulate alternative proteins. In 2020, Singapore became the first country to grant commercial authorisation of lab-grown meat (BBC, 2020[36]), while the United States approved the sale of meat grown from stem cells in July 2023 (NYT, 2023[37]). The Netherlands recently created a 'code of practice' to allow experimental tastings of lab-grown meat in controlled environments (EFANews, 2023[38]) while Italy banned its production and sale in 2023 (Governo.it, 2023[39]). Plant-based alternatives generally don't require specific regulatory approval and are treated similarly to other non-animal foods. The EU requires a scientific evaluation of insect-based products before commercialisation, while other countries (e.g. United States, New Zealand and Australia) often do not characterise them as "novel products" and do not have particularly burdensome approval procedures (Frezal, 2022[34]).

A transition to plant-based diets is projected to cost USD 30 billion, but the predicted economic benefits of this transition, totalling around USD 1.28 trillion, eclipse these costs (Nature, 2019[40]). There are now almost 1 500 manufacturers or brands, and more than 500 suppliers of key ingredients, for alternative proteins globally (The Good Food Institute, 2023[41]). Venture capital investments reached a record USD 5 billion in 2021, and are projected to grow exponentially to almost USD 300 billion by 2035 (Witte et al., 2021[42]).

Table 1. Net soil carbon sequestration measures on agricultural lands

Measure category	Measure	Land type	
		Cropland	Grassland
Carbonation	Mineral carbonation of soil	✓	✓
Erosion control	Prevent / control soil erosion	✓	✓
Fire management	Fire management	✓	✓
Grazing land management	Optimise stocking density		✓
	Pasture renovation		✓
	Sward management, bio nitrogen fixation		✓
Improved rotations	Perennial crops	✓	
	Catch crops	✓	
	Cover cropping	✓	
	Cover cropping with legumes	✓	
	Cultivated crops to increase soil carbon e.g. deep-rooted		✓
Management of organic soils	Restoration of cultivated organic soils	✓	
	Prevent degradation of organic soils	✓	
Nutrient management	Optimise nutrient inputs	✓	✓
Organic resource management	Residue retention	✓	
	Organic amendments	✓	✓
	Biochar	✓	
pH management	Keep pH at optimum for plant growth e.g. liming	✓	✓
Tillage management	Reduced tillage / no till	✓	
Water management	Soil water management	✓	✓

Note: There is some evidence that the integration of crop and livestock production systems, including the introduction of grass leys can increase soil carbon stocks. However, crop-livestock integration measures are not covered in this report.
Source: (Henderson et al., 2022[43]).

Reducing food loss along supply chains will be critical for reducing emissions

Reducing food loss is imperative to decreasing emissions. According to the United Nations Food and Agriculture Organisation (FAO), around 14% of food is lost along the supply chain. Substantial GHG emissions reductions can be achieved by ensuring that all produced food reaches final consumers. Better crop quality and resilience, better harvest timing, and improvements to harvesting equipment can all contribute to reducing food loss at the production stage, while better storage infrastructure, processing facilities, and logistical chains are needed in subsequent value chain phases (OECD, 2022[2]).

Further research is needed for better integration of food systems into economy-wide climate policies

Another important policy area concerns better integration of food systems into other economy-wide climate policies. For example, agricultural emissions tend to be excluded from most national carbon pricing schemes. This is in part because of measurement and reporting and verification (MRV) challenges (see Box 3) which make it difficult to systematically report on farm-to-fork emissions of particular food products, and harder to implement compliance-based carbon pricing obligations for the agricultural sector. Headway is being made with improved measurement methodologies, models and measurement technologies, however.

Additionally, carbon pricing for food products may face significant political challenges due to their impacts on reducing producer incomes and on raising food prices for consumers, notably as low-income households spend a high proportion of their income on food. Abatement subsidies may offer an alternative to emission taxation but will be challenging to fund, especially as mitigation needs rise over time. Overcoming these challenges could enable pricing systems to increasingly cover agricultural GHG emissions, helping to minimise overall costs on the way towards net-zero emissions.

Box 3. Food product carbon footprint measurement challenges and solutions

One cannot manage what one cannot measure. The objective of transforming food systems for net zero is no exception, and better understanding the emissions footprint of individual products, companies and projects is an important prerequisite for making faster progress. Policies and regulations are likely to require producers to measure and report on emissions footprints, which may have economic and trade-related impacts in addition to raising technical challenges. Even if such information is not required by law, better emissions reporting may become a *de facto* requirement for access to some markets if major retailers start to require it, driven by increasing consumer awareness and concern for climate change and environmental issues.

The complexity of emissions sources across food systems – including direct and indirect farm-level emissions, multiple greenhouse gases, and complex process supply chains – makes direct measurement of emissions challenging. Emissions are usually reported using modelling or proxy methods that are not always consistent with one another, raising questions around accuracy, comparability and fairness, including related to international trade, and questions of market access for producers in developing countries. Over time, improved technologies may enable widespread adoption of direct measurement techniques, including remote sensing via satellites.

In the near term, there is a risk of fragmentation and confusion due to rapid development of a large number of different footprinting standards and methodologies being developed internationally and across the private sector. These may take different approaches to important questions such as the scope of emissions included and approaches for estimating emissions where data is lacking.

Governments can do more to engage with stakeholders involved in the development of these standards and methodologies to better understand similarities and divergences and to encourage interoperability or harmonisation, to introduce public standards where appropriate and develop public databases. This can help to keep reporting costs down for domestic and international producers.

Source: drawn from "Carbon Footprints for Food Systems", background note prepared for the 2023 OECD Global Forum on Agriculture.

Demand-side options

Governments can also explore policies that influence the demand side of food systems, with a focus on OECD countries. This can include information and labelling schemes that aim to shift diets and preferences towards lower-emission alternatives, for instance by providing information on carbon footprints. Such policies need to be carefully designed to garner strong public support, given political and consumer sensitivities around food choices and cultural habits. International co-operation is necessary to ensure the interoperability of such labels across countries in order to maintain the food security benefits of international food trade. Challenges to measurement, reporting and verification (MRV) need to be addressed (Box 3).

Demand-side policies can also focus on food waste reduction, not only by informing and incentivising consumers and the food service industry to be more alert to food waste, but also by regulating retailers, for example by limiting "multi-buy" special offers.

Public procurement can also play a role in creating markets and demand for food products with lower emissions intensity while simultaneously helping to change preferences and behaviours. One example is introducing requirements for government-funded meals to include low carbon options. For example, in 2022, the US state of California committed USD 700 million to expand plant-based meals in schools, including both procurement of food and upgrading of needed services and infrastructure (FOE, 2022[44]).

Action is needed to address food waste at the consumer level

Promoting/directing behavioural changes and consumer awareness can significantly reduce food waste (Table 1), including through incentivising changes in retailer and business practices such as reporting and consumer targeting, introducing longer-lasting products or regulating commercial practices that lead to overbuying (OECD, 2022[2]).

Table 2. Average food waste estimates for households, food service and retail

	Average food waste (kg/capita/year)		Global food waste in 2019 (Mt)
	High-income countries	World	
Households	79	74	569
Food services	26	32	244
Retail	13	15	118
Total	118	121	931

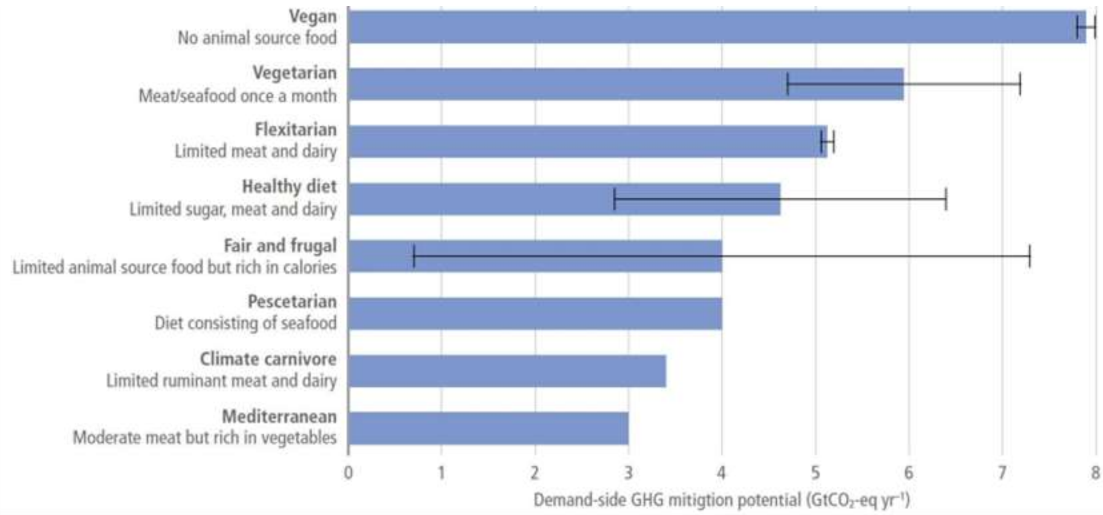
Note: World estimates are based on a sample covering 75% of the world population for Household, 32% for Food services and 14% for Retail.
Source: UNEP, 2021 in (OECD, 2022[2]).

Changing diets may also play a role

According to a broad literature review by the IPCC, dietary shifts in developed countries, such as to Mediterranean (less meat, more vegetables), vegetarian (no meat), pescatarian (no meat, more seafood proteins) and vegan (only plant based proteins) are shown to have considerable mitigation potential (Figure 6) and may lead to substantial health co-benefits (Tilman and Clark, 2014 in (OECD, 2022[2])). Estimates indicate that there is considerable scope for reducing animal-based protein intake in developed economies while still meeting recommended dietary requirements (OECD, 2022[2]). Results from scenario analysis suggest that a shift from meat to alternatives in high and upper middle-income countries would lead to 1.3% - 5% decline in global emissions from the AFOLU sector (Frezal, 2022[34]).

Affordability, taste, nutrition and freshness are the main priorities of households when purchasing food across income groups according to the 2023 OECD EPIC Survey (OECD, 2023[24]), thus suggesting that messaging on environmental issues alone will not be sufficient to lead consumers towards greener food choices. Higher consumption of meat, seafood and dairy products is often correlated with income: 29% of survey respondents in higher-income households report eating meat several times a week, compared to 20% of respondents in lower-income households (OECD, 2023[24]).

Figure 5. Technical GHG mitigation potential of changing diets



Note: Data without error bars are from one study only. All diets need to provide a full complement of nutritional quality, including micronutrients.
Source: (Mbow, 2019[45]) in (IPCC, 2019[19]).

It is crucial that low-GHG emission diets are also healthy. Significant evidence suggests that dietary patterns higher in plant-based foods, capped at the number of calories and lower in animal-based foods can lead to lower emission and better health. Importantly, healthy diets per se are not necessarily sustainable and vice versa (IPCC, 2019[1]).

While shifts towards diets based on alternative proteins offer considerable mitigation potential, millions of agricultural sector livelihoods depend on livestock farming and so dietary transformation would need to be progressive and context-specific, with sufficient safety nets for those negatively affected, as well as awareness of interlinkages between diets and cultural considerations. Policy makers will need to be vigilant in ensuring that their decisions are based on concrete evidence and effectively manage diverging interests and values in their implementation.

Synergies and trade-offs between food systems and environmental goals

Many options for reducing food system emissions represent win-wins for a more productive and resilient sector (Mirzabaev et al., 2021[27]). For example, more efficient fertiliser use and efforts to fix nitrogen through crop management and rotations would also reduce environmental pressures from nutrient leakage and fertiliser runoff and increase soil fertility. Afforestation can also avoid soil erosion and desertification, with benefits for biodiversity.

However, there are also potential trade-offs. Enhanced irrigation may increase drought resilience, food security and farmer livelihoods, but exacerbate water shortages elsewhere (OECD, 2015[46]).

Organic agriculture can achieve better environmental impacts per unit of land used through lower use of inputs, but there is debate about its impact on emissions. Some research suggests that greenhouse gas emissions from organic farming are similar to conventional systems per unit of food (Clark and Tilman, 2017 in (OECD, 2021[10])). However, more land is needed to compensate for lower outputs, implying important trade-offs for environmental and food security goals.

Both intensive and extensive agriculture practices could help to meet the projected increase in food demand and food security goals, but have very different environmental implications.

For crops, extensive practices entail increasing the amount of land used for agriculture. This could work against mitigation efforts by increasing deforestation. That said, intensive practices for crops can involve larger use of inputs such as fertilisers and water. This more intensive use of inputs reduces the need for additional land, but may lead to higher GHG emissions from inputs use and production on a per-unit-of-land basis. Both approaches can have negative implications for biodiversity because of further loss of natural land in the case of extensive approaches and of lower in-farm biodiversity in case of intensive approaches. Input-based intensification can also have additional negative environmental impact on water cycles due to acidification of freshwater ecosystems and eutrophication due to nitrogen pollution. As noted above, increasing sustainable total factor productivity growth, notably through innovation, will be critical in meeting the triple challenge.

For livestock, extensive (grass-fed) systems use substantial land area for grazing and result in higher emissions per unit of product. Intensive animal production (including raising animals in feedlots) can reduce emissions per unit of output and direct land use, but can increase environmental impacts related to higher nutrient loading per unit of land, and can conflict with animal welfare goals. Intensive systems also require use of land for feed production, which in turn generates environmental impacts.

Conclusion

Tackling the climate challenge in agriculture is a complex task, as emissions reductions must be achieved while facilitating adaptation to climate impacts in order to minimise adverse effects on food security and nutrition, safeguard livelihoods and protect the environment. Nonetheless, there is still considerable scope for action. Robust policy responses, taking into account local contexts as well as international commitments, will be crucial for navigating obstacles and building trust to address the triple challenge facing food systems.

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