6 Transforming food systems

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6.1 Introduction

Food systems are major contributors to climate change and other environmental problems, such as land-use change and biodiversity loss, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems through nitrogen and phosphorus run-off from fertilizer and manure application (Cordell and White 2014; Crippa *et al.* 2021; Diaz and Rosenberg 2008; Foley *et al.* 2005; Newbold *et al.* 2015; Robertson and Vitousek 2009; Shiklomanov and Rodda 2004; Intergovernmental Panel on Climate Change [IPCC] 2019; Wada *et al.* 2010; Willett *et al.* 2019).

If current trends continue, the environmental pressures on food systems are likely to intensify (Jalava *et al.* 2014; Tilman and Clark 2014; Davis *et al.* 2016; Springmann *et al.* 2016; Springmann, Clark *et al.* 2018). Key targets of several Sustainable Development Goals (SDGs) are projected to be at risk (Springmann, Clark *et al.* 2018; Springmann *et al.* 2020), and the greenhouse gas (GHG) emissions from food systems could, on their own, preclude achieving the Paris Agreement goal of limiting global warming to below 2°C, aiming for 1.5°C (Clark *et al.* 2020). Transforming food systems is therefore imperative for avoiding dangerous levels of climate change and other environmental problems.

Moreover, transforming food systems is not only important for addressing climate change and environmental degradation, but also essential for ensuring healthy diets and food security for all. Currently, imbalanced diets that are low in fruits, vegetables, nuts and whole grains and high in red and processed meat are a leading health burden in most regions and are responsible for more than one in five premature deaths globally (GBD 2017 Diet Collaborators 2019; Springmann, Mozaffarian *et al.* 2021). In addition, about 2 billion people are overweight and obese, and 2 billion have nutritional deficiencies, while about 800 million are still suffering from hunger due to poverty and poorly developed food systems (Food and Agriculture Organization of the United Nations [FAO] *et al.* 2020). As the dietary transition towards more processed and high-value products continues in many regions of the world, these dietary health risks are expected to worsen (Springmann *et al.* 2016; Springmann, Wiebe *et al.* 2018).

At the same time, many of the world's poor cannot afford to pay for healthy and sustainable diets (FAO *et al.* 2020; Springmann, Clark *et al.* 2021), and the ongoing crises caused by COVID-19, the war in Ukraine, and widespread extreme climate events are further exacerbating this situation by disrupting food systems and increasing the costs of foods (Guénette, Kose and Sugawara 2022; Organisation for Economic Co-operation and Development [OECD] 2020; Ogundeji and Okolie 2022) (see box 6.1).

Adopting a food systems lens can help in identifying the synergies and trade-offs across the various interconnected environmental, health and economic impacts. Compared to the traditional categorization of agriculture, forestry and other land use (AFOLU), food systems include pre- and post-production processes, which are related to the transportation, industrial activities, storage and consumption of food (IPCC 2019; Rosenzweig *et al.* 2020). The inclusion of several sectors makes the computation of food system emissions more difficult and increases the risk of double counting when summed with and compared to individual sectors (figure 6.1). However, having a food systems approach that explicitly connects the supply and demand sides and all the actors of the food supply chain has many advantages. It ensures that climate change mitigation strategies are compatible with food security, and facilitates the design of integrated adaptation and mitigation policies, including their trade-offs and synergies (Rosenzweig *et al.* 2020). This is particularly important in the current context in which multiple crises impact the supply and demand of food.

This chapter presents the needs, current state and options for accelerating a food system transformation. It focuses on GHG emissions and climate change, but also discusses important synergies and trade-offs with the environmental, health, and economic/equity dimensions throughout the chapter. The chapter will present and discuss transformative solutions that can decrease emissions in the supply and demand side of food systems along with examples of initiatives already in place in various parts of the world. It will also discuss how further actions can be accelerated to ensure that food systems contribute their share to fulfilling the goals of the Paris Agreement.

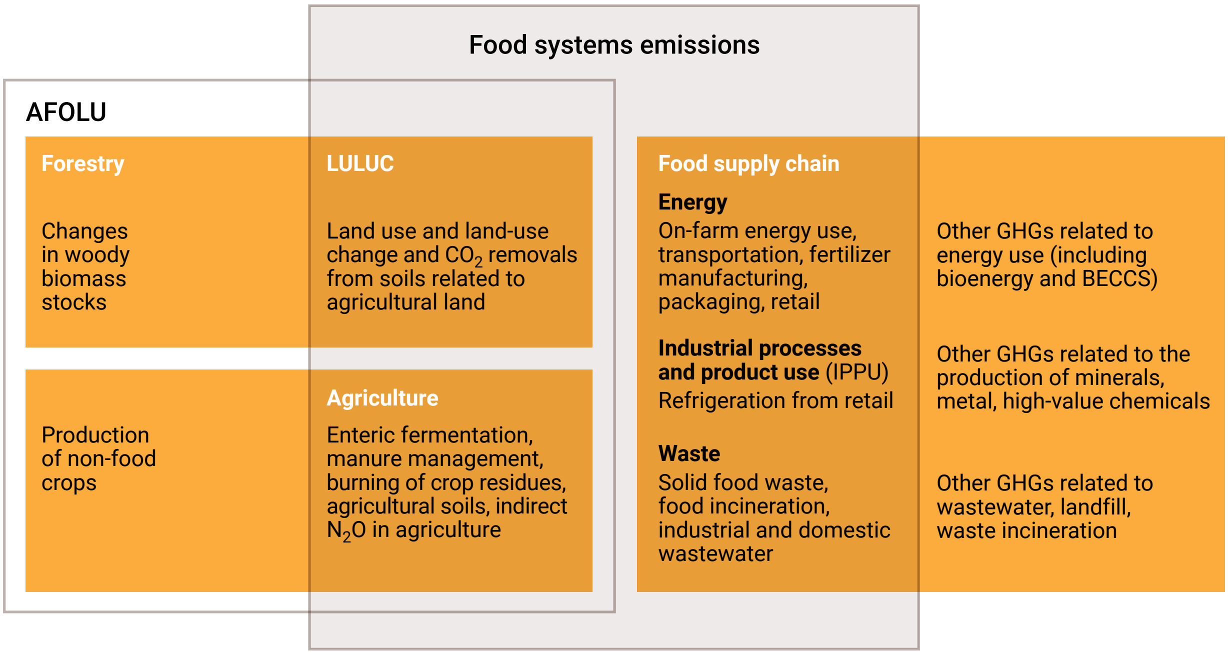
Box 6.1 Equity and justice as vital components to accelerate transformations of food systems

Although any climate stabilization pathway requires a substantial reduction in emissions from food systems, such mitigation efforts must not come at the expense of the health and livelihoods of low-income populations. At a per-person level, the richest 10 per cent of the world's population produces the highest emissions, while the poorest produce the least emissions and suffer the highest consequences of climate change due to their socioeconomic status and reduced adaptive capacities. In 2021, approximately 828 million people were affected by hunger globally, and this figure is estimated to continue increasing with the instability caused by COVID-19 and the war in Ukraine. The current rise in inflation and energy prices adds further pressure to the world's food supply chain. These adverse impacts concern everyone, but they are especially felt by the poorest and the most vulnerable in society, the majority of whom are women.

Better distribution of food and more efficient use of resource is essential to fight food insecurity and malnutrition within the decade (FAO *et al.* 2022). Reducing the use of much of the world's grain production to feed animals and producing more food for direct human consumption can significantly contribute to this objective (IPCC 2022a). In most high and middle-income countries, healthier and more sustainable diets can be cheaper than current diets, but in many low-income countries, they are higher in cost than the prevalent starch-based diets (FAO *et al.* 2020; Springmann, Clark *et al.* 2021). Making healthy and sustainable diets affordable for all is possible, but will require dedicated food system interventions in low-income settings (Springmann, Clark *et al.* 2021).

Poverty alleviation remains a prime goal of low-income countries, and agricultural development will remain a key part of their development strategies, with climate actions more focused on adaptation than mitigation. Climate-resilient development in Africa's rural areas, if it is to tackle entrenched chronic poverty, will need to be transformational, with elements of farm consolidation, irrigation development, improved fertilizer usage, increased market access and enhanced social safety nets, among other elements (Orr *et al.* 2013; Beegle, Coudouel and Monsalve 2018; Lefore *et al.* 2019; Giller 2022). Some of the expected changes can produce mitigation co-benefits, but in other cases food system emissions are likely to rise (Springmann, Wiebe *et al.* 2018). An important objective is therefore to ensure that rural transformation is placed on a low emissions trajectory.

Figure 6.1 Classification of food systems emissions and the difference to standard emissions categories of the IPCC



Notes: The IPCC categories included in food systems are shown within the faded grey square. This figure shows the main differences and overlaps with the more traditional IPCC category of AFOLU (Crippa *et al.* 2021; IPCC 2019). For all official IPCC categories, only parts are included in food systems. Although some agricultural production is dedicated to non-food uses, non-food crops only represent 2 per cent of the emissions, so most of agricultural production is included in food systems. From the category land use, land-use change and forestry (LULUCF), we only include emissions from land use and land-use change within food systems. Thus, emissions and/or sequestration in remaining forest land are excluded from food systems. We followed FAO's definition for the categories energy, industrial processes and product use (IPPU), and waste (Tubiello *et al.* 2021).

6.2 Transformation needs and potential

The food system is currently responsible for about a third of total GHG emissions or 18 (range: 14–22) gigatons of CO_2 equivalent ($GtCO_2e$) per year (IPCC 2019; Crippa *et al.* 2021). The largest contribution stems from agricultural production (7.1 $GtCO_2e$, 39 per cent) including the production of inputs such as fertilizers, followed by changes in land use (5.7 $GtCO_2e$, 32 per cent), and supply chain activities (5.2 $GtCO_2e$, 29 per cent). The latter includes retail, transport, consumption, fuel production, waste management, industrial processes and packaging. Developing countries currently contribute about three quarters (73 per cent) of emissions from food systems, but given their large populations, per capita emission footprints are up to four times lower than those in industrialized countries (Crippa *et al.* 2021). Food system emissions are projected to increase by up to 60–90 per cent between 2010 and 2050 without dedicated measures and if current trends continue with respect to population growth and dietary changes towards more animal source foods, especially in low and middle-income countries (Riahi *et al.* 2017; Springmann, Clark *et al.* 2018; Mbow *et al.* 2020).

Both the current and the projected levels of food system emissions are at odds with the scale of rapid emissions reductions needed across all sectors to achieve the Paris Agreement goals (Clark *et al.* 2020; IPCC 2022b). Even if fossil fuel emissions were quickly reduced, food system emissions could prevent achieving the well below 2°C, preferably 1.5°C goal by the end of the century (Clark *et al.* 2020). For having a 66 per cent chance of limiting global warming to below 2°C, estimates from integrated assessment models have suggested a limit of agricultural emissions (i.e. methane and nitrous oxide) of about 5 $GtCO_2e$ in 2050, in addition to decarbonizing the energy system and limiting emissions from land-use changes (Costa *et al.* 2022; Willett *et al.* 2019).

A range of transformation domains with several mitigation measures have been identified where food systems can contribute to bridge the emissions gap (Springmann, Clark, *et al.* 2018; Roe *et al.* 2019; Clark *et al.* 2020; IPCC 2022b). They include:

1) **demand-side changes**, including dietary changes towards sustainable and nutritionally balanced diets, and reductions in food loss and waste,

2) **protection of natural ecosystems**, including reductions in deforestation for agriculture and degradation of agricultural land,

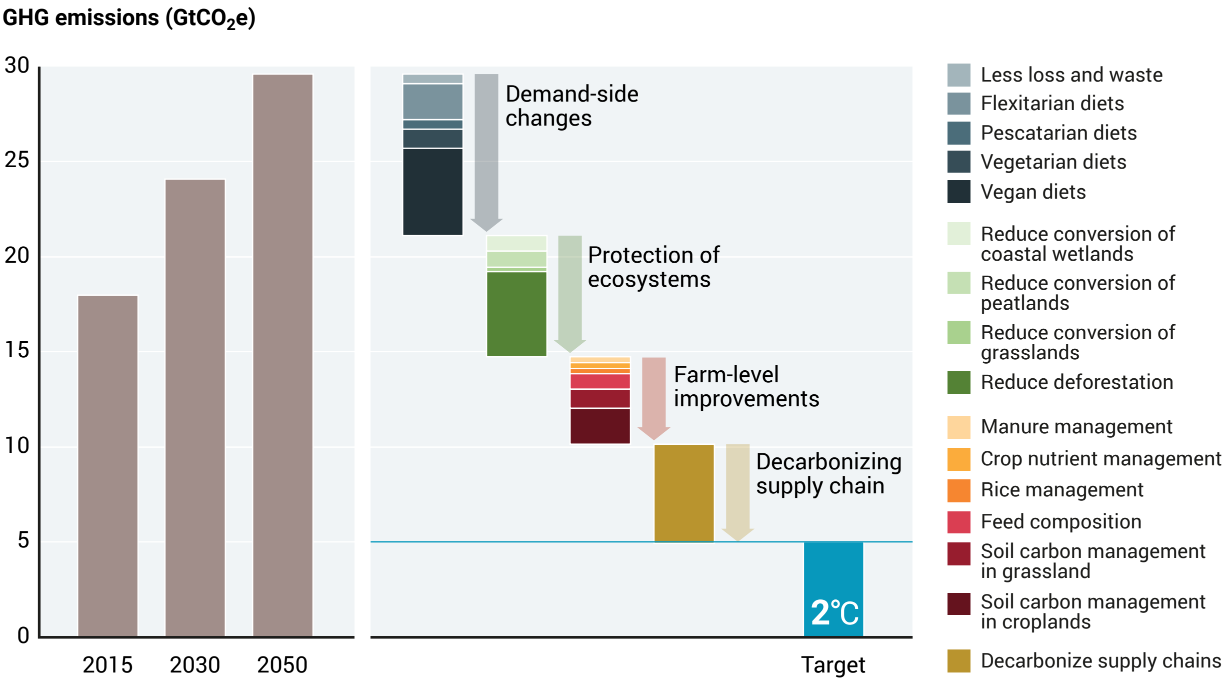
3) **improvements in food production at the farm level**, including changes in the composition of animal feeds, better rice management, better manure management, and improvements in crop nutrient management, and

4) **decarbonizing the food supply chain**, including in retail, transport, fuel use, industrial processes, waste management and packaging.

Figure 6.2 provides an overview of the mitigation potentials of the different measures. We focus on the technical mitigation potentials in the figure, but note that economic potentials (i.e. those achievable below a cost of carbon of US$100/t$CO_2$e) are much lower and often just half of the technically achievable potential (IPCC 2022b). To avoid double counting in these estimates, the chapter isolates the demand-side impacts from land use and technical improvements at the farm level. However, any one domain will generally be affected by changes in any other domain. For example, dietary changes towards more plant-based diets will reduce the demand for cropland that then eases measures to reduce deforestation. In addition, each estimate is subject to considerable uncertainty. This is especially evident for technologies or management practices that have not yet been proven to work at scale, including bioenergy with carbon capture and storage (Low and Schäfer 2020) and a range of soil-related activities often classified as regenerative agriculture (Willett *et al.* 2019; Giller 2022). What is clear however is that there is no simple solution, and a combination of measures will be needed to transform food systems in line with targets and pathways for reducing emissions.

When combining mitigation measures, care will have to be taken to avoid trade-offs with other issues of concern, including food security and health, and instead generate synergies. Especially when it comes to food and diets, important synergies exist across the public health concerns for the provision of healthy diets and the elimination of malnutrition and the climate change concern for reducing emissions (Springmann, Wiebe *et al.* 2018; Willett *et al.* 2019).

Figure 6.2 Food systems emissions trajectory and mitigation potentials by transformation domain



Notes: Current food systems emissions were adapted from Crippa *et al.* (2021), future projections from Costa *et al.* (2022) and the target value for limiting global warming to below 2°C from Willett *et al.* (2019). The projections of future emissions are based on life cycle assessments that include all GHG emissions and land-use effects but hold technologies constant at current levels. The mitigation potentials denote technical potentials and, except for diet changes and supply chains, were adopted from the IPCC *Sixth Assessment Report* (AR6) (2022b). The potentials for dietary changes were updated based on Springmann *et al.* (2018), which are controlled for double counting and include all GHG emissions except those for land-use changes. The estimate of current supply chain emissions from Crippa *et al.* (2021) was used as an illustrative value for mitigation potential for decarbonizing supply chains.

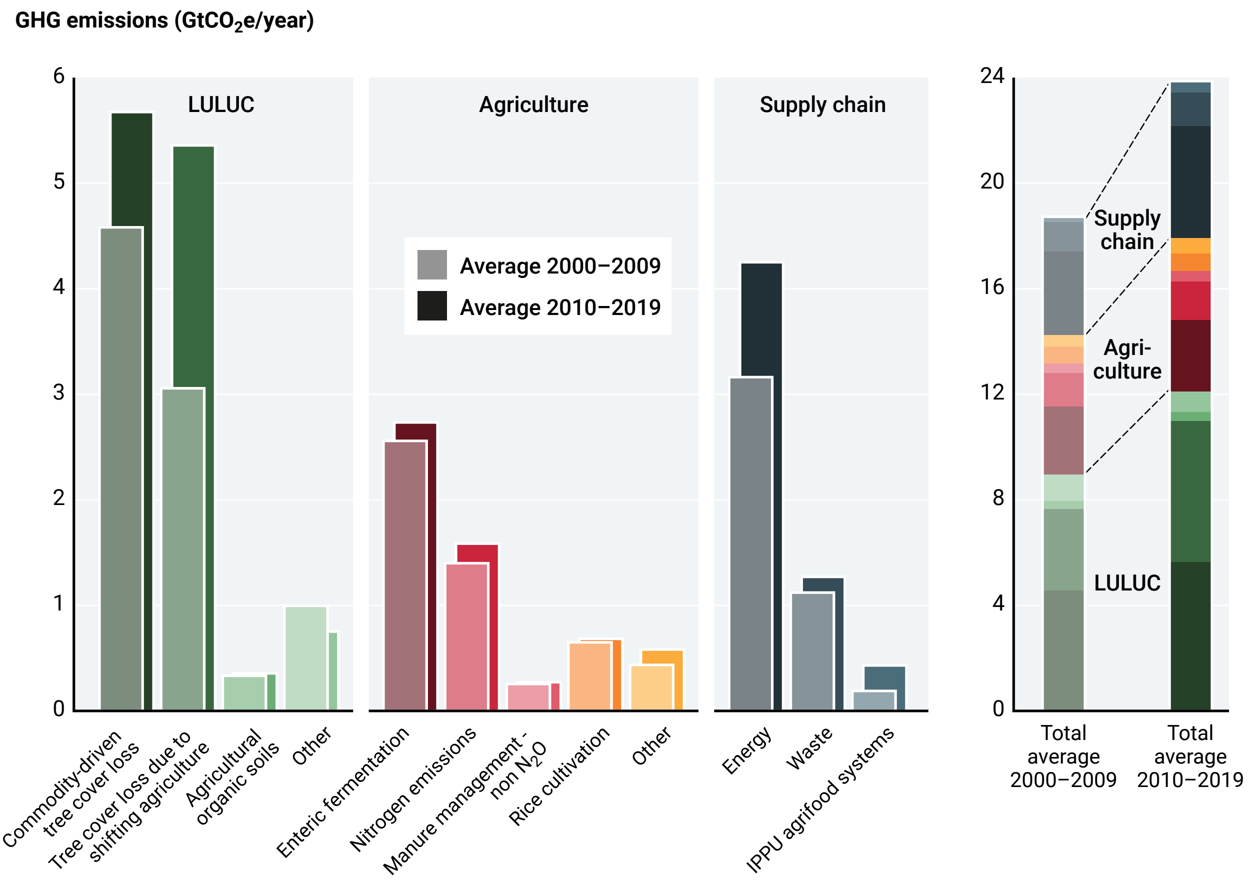
Within demand-side changes, the mitigation potentials of the different diets are displayed as marginal changes to avoid double counting and to allow the adding up of contributions within this category. This means that the bar for vegan diets denotes the maximum achievable mitigation potential that is composed of its own bar and the bars for vegetarian, pescatarian and flexitarian diets.

6.3 Signs of progress and options for further action

The evolution of global GHG emissions per transformation domain highlights signs of progress and options for further action. It also shows some encouraging examples across the world. Global food system emissions have increased during the last two decades (figure 6.3). Emissions from agriculture have only slightly increased, while emissions from the food supply chain have dramatically increased (FAO 2021a; Ritchie 2019).

The following examines key subcategories within each transformation domain to get a more detailed understanding of their relative importance and discuss concrete mitigation options. The selected subcategories are meat consumption for demand-side changes, deforestation for the protection of natural ecosystems, nitrous oxide emissions from agricultural soils for improvements in food production at farm level, and energy use in food systems for decarbonizing the food supply chain. Figure 6.3 shows the evolution of emissions by subcategories. These subcategories together account for more than half of total emissions from food systems.

Figure 6.3 Average global annual emissions from food systems between 2000–2009 and 2010–2019



Source: The GHG emissions from food systems supply chain, agriculture, and land use and land-use change (LULUC) excluding forest cover change are taken from FAOSTAT Emissions shares and Emissions Totals (Tubiello *et al.* 2021). Emissions from tree cover loss are taken from Global Forest Watch (Curtis *et al.* 2018). This selection leads to higher total emissions from food systems than Crippa *et al.* (2021), Tubiello *et al.* (2022), and Costa *et al.* (2022).

6.3.1 Sustainable and nutritionally balanced diets

The production of meat was responsible for approximately 54 per cent of GHG emissions from agriculture between 2018 and 2020 (OECD and FAO 2021). Life cycle analyses indicate that meat production—from inputs in its production to retail—has a median value of CO_2e per 100g of protein that is significantly higher than alternative plant-based sources of protein (Poore and Nemecek 2018). For example, beef has a median GHG intensity that is more than 5–10 times higher than pork and poultry, and 50–100 times higher than plant-based protein sources such as beans and lentils. In addition to the climate benefits, eating less red meat, only moderate amounts of poultry, seafood and lean fish as well as increasing the intake of plant-based foods is associated with a lower risk of major chronic diseases (Springmann, Wiebe *et al.* 2018; FAO and WHO 2019; Willett *et al.* 2019).

The production of meat has more than quadrupled since the 1960s (Ritchie 2019). However, developments in how much meat individuals consume per country have been uneven. We see a high correlation between meat consumption and income level. The average daily meat consumption per capita varies from around 25g in low- and lower-middle-income countries which as a total is within the range of recommended intake, but red meat consumption alone is above the recommended levels. In upper-middle-income countries and high-income countries, average meat consumption is far above recommended levels with 105g/cap/d in upper-middle-income countries and 154g/cap/d in high-income countries. In many industrialized countries where the per capita red meat consumption has started to decrease it is partly compensated by an increase in poultry consumption.

These trends show that progress on changing diets has been very limited. This is also reflected in a review of the nationally determined contributions (NDCs) that shows the inaction towards reducing meat consumption both in high-income and higher-middle-income countries (box 6.2). Meat production is projected to increase more than 60 per cent between 2010 and 2050, primarily being driven by population and economic growth, especially in low- and middle-income countries. However, if everybody on the planet consumed within levels recommended for health and the environment (14 g/d or less of red meat, 29 g/d or less of poultry, and 28 g/d or less of fish), meat production would not need to increase beyond current levels (Springmann, Clark *et al.* 2018).

Table 6.1 Examples of positive shifts in meat consumption

Area	Positive shifts
Slovenia, Uruguay and Ecuador*	Average per capita meat consumption between 2010 and 2019 has decreased despite economic growth (Ritchie 2019). More research is needed to highlight the determinants of this change.
Europe and North America*	Vegetarian diets are increasing in popularity. Non-meat consumers represent between 5 and 10 per cent of the total population (Kansas State University 2022; Lusk and Norwood 2016).
Global	Total consumption of meat substitutes has increased by more than three times, and total consumption of milk substitutes has almost doubled between 2013 and 2020 (Friedlingstein *et al.* 2022).

* In these areas, meat consumption currently far exceeds recommended levels.

Box 6.2 Coverage of food system in revised NDCs

Currently, all NDCs include food systems. However, demand-side measures and actions to reduce emissions from food processing, storage and transportation of the food systems are frequently overlooked (Food and Land Use Coalition [FOLU] and Food, Environment, Land and Development Action Tracker 2021; Global Alliance for the Future of Food 2022; Hamilton *et al.* 2021). None of the revised NDCs submitted ahead of the 2021 United Nations Climate Change Conference of the Parties (COP 26) mention the need to reduce the consumption of animal protein. Food loss and waste are only covered in a few NDCs including the ones for the United Kingdom, the European Union, France and South Africa (Global Alliance for the Future of Food, 2022). On the production side, the agriculture and land use sectors feature prominently in the NDCs of developing countries with 86 per cent prioritizing mitigation in these sectors (Crumpler *et al.* 2021), but sustainable livestock production could be better covered, especially by large meat producing countries (Global Alliance for the Future of Food, 2022). Agroecology and regenerative approaches are common, but a clear operational definition of regenerative agriculture is needed. Except for Colombia, food systems actors tended to be overlooked in domestic consultation processes which has likely led to gaps in food systems coverage in the NDCs.

With new data available in FAOSTAT Emissions shares and the Emissions Database for Global Atmosphere Research's global food emission (EDGAR-FOOD) databases (Crippa *et al.* 2022) released in 2021, quantifying and discerning food systems-related emissions and acquiring data on emission patterns has improved. This should facilitate the coverage of food systems in future NDCs (Crippa *et al.* 2021).

6.3.1 Protection of remaining natural ecosystems

For this transformation domain, the selected subcategory is deforestation, the main source of emissions from LULUC (figure 6.3). Deforestation also reduces the future removals of atmospheric carbon in natural forests, further exacerbating climate change (Maxwell *et al.* 2019). At the global level, food systems can be directly related to almost half of tree cover loss through commodity-driven deforestation and shifting agriculture, and the contribution could be higher if linked to wildfires (Curtis *et al.* 2018; Pendrill *et al.* 2022). Halting deforestation therefore is key for both environment protection and climate change mitigation. The SDGs include a target of halting deforestation by 2020 (target 15.1), and the objective has been restated in several declarations e.g. during COP 26 with the Glasgow Leaders' Declaration on Forests and Land Use.

Despite all these commitments, deforestation related to food systems has continued to increase from 8 million hectares (Mha) per year in 2001–2010 to 11.5 Mha/year in 2011–2020 according to statistics from the Global Forest Watch (GFW) on tree cover loss driven by commodities and shifting agriculture (GFW 2022). It is estimated that 29–39 per cent of emissions were driven by international trade (Pendrill *et al.* 2019).

Global GHG emissions estimates for deforestation in 2001–2020 vary between 3.4 and 9.5 $GtCO_2$ per year on average (FAO 2021a; Grassi *et al.* 2022; Friedlingstein *et al.* 2022; GFW 2022). Differences can be partly explained due to differences in definitions of forests and deforestation. Uncertainty in carbon stocks in forests is another source of variation across estimates, especially at fine scales.

Without new forest conservation policies, 289 million hectares of tropical forest could be cleared by 2050 (Busch and Engelmann 2017) and have dramatic impacts on climate change, traditional livelihoods, human health, biodiversity loss and ecosystem services.

With less than eight years to close the emissions gap there is a need for effective, unified and public systems of monitoring, reporting and verification (MRV) of deforestation to make governments and companies accountable for their deforestation commitments (Nabuurs *et al.* 2022). Local communities and traditionally marginalized groups such as indigenous communities inhabiting and or living close to forested areas are deeply vulnerable to the impacts of deforestation and therefore should be closely involved (FAO 2022). Their contributions and knowledge are invaluable and can help to address important sources of risk.

Table 6.2 Examples of positive shifts in addressing deforestation

Area	Positive shifts
Brazil	There was an impressive slowdown in deforestation in the Brazilian Amazon between 2005 and 2011. The combination of real-time monitoring (Real Time Deforestation Detection System), public release of annual deforestation data (Basin Restoration Program), strong law enforcement, expansion of protected territory and adoption of a conditional rural credit policy has been key to curbing deforestation during that period (Assunção, Gandour and Rocha 2015). Unfortunately, political changes mean that deforestation has increased again since then, even if it remains below its peak in 2005 (zu Ermgassen *et al.* 2020).
Indonesia	Deforestation in Indonesia has been reduced for the fourth year in a row (GFW 2022; Gaveau *et al.* 2022). The moratorium on new licences for primary forests and peatlands introduced in 2011 has played an important role to reduce conversion of natural forests and peatland drainage to install timber or oil palm plantations. More than 80 per cent of the oil palm refining capacities and the pulp and paper industry in Indonesia have also committed to 'No Deforestation, No Peat and No Exploitation'.
European Union	In September 2022, the European Parliament voted to enable a law that conditions farmers to document that products being sold to the European Union are neither involved with human rights abuse nor deforestation. Being responsible for approximately 16 per cent of deforestation in the tropics (Pacheco *et al.* 2021), the European Union can address its consumption of products associated with ecosystem degradation to have real impacts.

6.3.2 Reduction of emissions from agricultural production

Enteric fermentation of ruminant livestock is the major source of emissions from agricultural production. beyond changes in diets, the reduction of methane emissions from ruminants can be achieved through changes in feed level and feed composition, which can also increase animal productivity (Frank *et al.* 2018; Arndt *et al.* 2022).

Growing rice is another important source of emissions from agriculture, especially for low- and middle-income countries. Paddy farming relies on flooded cultivation fields that emit large quantities of methane into the atmosphere via anaerobic decomposition (Gupta *et al.* 2021). Changes in water management can significantly reduce methane emissions from rice (Islam 2021).

Another prominent GHG is nitrous oxide, which is mainly emitted from agricultural activities. This includes emissions from the application of synthetic fertilizers on agricultural land and from livestock manure that is either used as organic fertilizers for crops or left on pastures. In 2019, nitrous oxide emissions from soils represented 25 per cent of total agricultural emissions (FAO 2021a), making it the second largest source of emissions from agriculture after methane emissions. Production of synthetic fertilizers is also a large source of emissions from the supply chain. reducing on-farm synthetic fertilizer would therefore lead to a reduction in this source of emissions too. Tackling excessive on-farm nitrogen use carries important co-benefits for air pollution through reduced ammonia emissions that would otherwise contribute to particular matter concentrations, and for water quality, as excessive nitrogen use leads to the excessive growth of aquatic plants and algae that can reduce the diversity of animals and plants and compromise the possible uses of the affected water (de Vries 2021; Maúre *et al.* 2021).

Global nitrogen emissions from synthetic fertilizers and livestock manure have continued to grow after 2010, and the average annual emissions in 2010–2019 were 14 per cent higher than in 2000–2009 (FAO 2022). While average annual emissions have been nearly stable in high-income countries and only increased by 7 per cent in upper-middle-income countries, they have strongly increased in lower-middle-income and low-income countries (by 25 and 69 per cent, respectively). Reducing nitrogen use without impacting yield is not straightforward due to the fact that different crops have different needs independent of factors such as topography and slope (which can vary during the growing cycle), crop type and weather conditions (Sharma and Bali 2018).

From equity and food security perspectives, unequal access to fertilizers is an important area of concern. For example, judicious use of fertilizers and organic nutrients are essential to increasing crop productivity in large areas of inherently poor and highly weathered soils in Africa (Zingore and Njoroge 2022). For context, to achieve self-sufficiency in maize in nine countries in sub-Saharan Africa, maize yields would have to increase from about 20 per cent of water-limited yield potential currently to approximately 50–75 per cent of the potential, with nitrogen input rising disproportionately more (by 9–15 times) (Rurinda *et al.* 2020).

Table 6.3 Examples of positive shifts in emissions from agricultural production

Area	Positive shifts
China	Nitrogen emissions from synthetic fertilizers and livestock manure have reduced over the last three years because of a long focus on reducing fertilizer use. Since 2005, a policy on zero increase in chemical fertilizer use has been introduced (Wang *et al.* 2022) and a programme has been running to test soils and use fertilizers based on exact needs, with US$1.2 billion of government investment. The scheme has been applied on 100 Mha of land, which has increased the efficiency of fertilizer use by 5 per cent while increasing grain harvests by 6–10 per cent. In 2017, the Government of China started a five-pronged push to develop green agriculture. This included replacing chemical fertilizers with organic compost made from fruits, vegetables and tea (Kun and Genxing 2021).
Europe	Nitrous oxide emissions declined from 1990 levels (IPCC 2022b) and the nitrogen surplus applied to agricultural land was reduced by 18 per cent between 2000 and 2009, (Cook 2018), mainly thanks to public regulation. The European Union Nitrates Directive (91/676/EEC) was established in 1991 to balance fertilization requirements and prohibited nitrogen application during some periods (European Environment Agency 2020). This has been strengthened by other directives on improving the quality of water and setting emission reduction commitments by country, and policy instruments within the Common Agricultural Policy.
Denmark	From the 1980s, a wide range of policy instruments were introduced that led to a cut in nitrogen use by almost two between 1990 and 2011 without reduction of agricultural production (Petersen *et al.* 2021). A key factor of success was the definition of several action plans with clear targets that have been progressively adjusted according to the monitored progress. Introduction of farm-level nitrogen quotas has also proved to be costly but effective.

India	Legumes such as beans, peas and lentils increase the release of ammonium nitrogen into the soil. The greater availability of nitrogen in the soil can reduce the needs for nitrogen fertilizers for other crops when legumes are used in rotations or as cover crops or intercrops. India has observed a consistent increase in the production of legumes in the last five years. In 2020, some states decided to include pulses in the Public Distribution Package that previously only included wheat and rice to further encourage production.
North America	Precision farming techniques have increasingly been adopted. These include a management approach that focuses on (near real-time) observation, measurement and responses to variability in crops, fields and animals. However, it has not yet translated into lower nitrogen emissions. It is not so clear if even the most promising technologies for reduced nutrient use (Sharma and Bali 2018) can significantly reduce nitrogen input use and increase economic benefits (Späti, Huber and Finger 2021).
Viet Nam	The national strategy for achieving emission reductions in rice includes controlled water management, reduction of straw burning and conversion of inefficient rice land for other uses. Low-emission practices have already been successfully implemented in An Giang, a major rice-producing province in the Mekong Delta, contributing to a reduction of over 2 megatons (Mt) of CO_2e/year and improving smallholder famers' net income per hectare by 7–25 per cent through the use of alternate wetting and drying (Tran *et al.* 2019). In the Mekong, alternate wetting and drying could be practised on an additional 900,000 hectares, resulting in emission reductions of 10.97 MtCO_2e.
Global	The area under organic farming is increasing in all continents with close to 75 million ha globally in 2020 (1.6 per cent of global farmland) compared to 11 Mha in 1999 (Willer *et al.* 2021). The contribution of organic farming to the overall reduction in GHG emissions is debated because of indirect land-use effects due to lower yields and the increased manure-related emissions compared to synthetic fertilizers (Smith *et al.* 2019).

6.3.3 Decarbonizing the food supply chain

Energy use along the whole food supply chain is the source of emissions in the food systems that has grown the fastest during the last two decades. This covers emissions from on-farm fuel use for machinery and irrigation, food transportation, energy use for cooking, cooling and freezing in the food processing industry and for packaging, energy use within retail and supermarkets, and household food-related energy consumption. Household food-related energy consumption includes energy use related to travel to purchase foods, food storage in freezers/refrigerators, meal preparation and clean-up (Pelletier *et al.* 2011). Households represent 30 per cent of total food systems' energy emissions, while the retail and supermarket sector come second with 20 per cent of food systems' energy emissions (Tubiello *et al.* 2021), a number only expected to increase as supermarkets continue expanding in developing countries (Reardon, Timmer and Minten 2012). Despite a high average distance travelled for many food products (Pelletier *et al.* 2011), transport represents only between 5 and 11 per cent of total emissions from energy in the global food system (Poore and Nemecek, 2018; Tubiello *et al.* 2022).

The rapid growth in fluorinated gases (F-gases) emissions from cooling equipment used in the food chain, particularly in emerging economies, is worrying as F-gases greatly contribute to climate change due to their significantly higher warming potential than CO_2.

The food and beverage industry is a critical area of activity characterized by: a large geographical spread unlike many other industries, large multinational corporations alongside numerous small and medium enterprises, a broad heterogeneity of products that cut across very different processes, and stringent requirements related to rapid post-production shelf life and health considerations (Sovacool *et al.* 2021). This leads to specific mitigation options and potentials compared with other industries. The main options include improved management and technologies to increase energy use efficiency and better waste recovery and use of by-products (Sovacool *et al.* 2021). More generally, the food sector has great potential for adopting renewable sources of electricity or heat, especially biomass waste or biogas from anaerobic digestion. It is projected that renewable energy could cover 60 per cent of existing heat demands of the sector (International Renewable Energy Agency [IRENA] 2015). Simple things like putting doors on refrigerators in supermarkets could also help cut energy use, but this is often perceived as a sales barrier (Jesse, Perotti and Roos 2022).

Table 6.4 Examples of positive shifts in decarbonizing supply chains

Area	Positive shifts
Kenya	A major dairy processor has partnered with an off-grid solar technology provider to provide solar-powered irrigation to support fodder crops and water access for cattle, thus boosting milk production (IRENA and FAO 2021; Lukhanyu 2021).
Europe	A leading European dairy producer is working closely with almost 8,000 farms in seven countries to promote circular farming practices. As a result, the carbon footprint of milk production for the company is less than half the global average per kilogram (Jesse, Perotti and Roos 2022).

6.4 How can transformation be accelerated?

Although a food systems transformation is essential for limiting global warming and would have a number of other environmental, health, food security and equity benefits, little progress has been made in the last two decades (UNEP and UNDP 2021). In this final section, the role of different actors in accelerating transformations is discussed. Main actors include national governments, cities and local governments, the private sector, civil society and the scientific community.

6.4.1 National governments

At the national level, structures for food system governance that integrate relevant sectors and food system components are essential to drive transformative action (Springmann *et al.* 2020; Steiner *et al.* 2020). One of the first challenges to scaling transformations is the fragmentized state of data, information, knowledge and awareness across sectors, population groups and public and private agencies (OECD and FAO 2022). Multicomponent approaches that combine e.g. information campaigns with economic incentives and fiscal measures are more likely to lead to meaningful changes than the narrow focus on the provision of information that many governments have traditionally followed (Mozaffarian *et al.* 2012; Mozaffarian 2016).

Reforming national dietary guidelines can be a good start and help guide citizens make healthier and more sustainable food choices (e.g. Seychelles, Ministry of Health 2020), but this needs to be disseminated both through educational programmes and government-sponsored campaigns (Springmann *et al.* 2020), and combined with other measures such as mandatory labelling and the provision of additional information e.g. carbon footprint data. The practice of public institutions making their data sets available to the wider public ('open government data') allows citizens, civil society organizations and businesses to creatively use and combine these data, which may in turn lead to innovative ways of delivering public services (Deconinck *et al.* 2021) and increased trust for upcoming policy reforms.

Fiscal policies, including taxation and the provision of directed subsidies, is another measure that can contribute to food system transformation. A global analysis with country-level data has shown that taxing foods in accordance with their GHG emissions could improve diets and reduce emissions by about 1 $GtCO_2e$ for a modest carbon price of about US$50/$tCO_2e$ (Springmann *et al.* 2017). When examining subsidies, currently approximately 87 per cent of support to agricultural producers is either distorting prices or supporting approaches that are harmful to nature and health (UNEP and UNDP 2021). Reforms are necessary to direct subsidies to the production of healthy and more sustainable foods to increase their availability, reduce their prices and increase their consumption, which carries knock-on effects in the form of reduced GHG emissions (FOLU 2019; Springmann and Freund 2022).

Lastly, targeted investments and regulation can also play a role. Reducing on-farm emissions will require increased investment in public infrastructure such as storage or waste management. Moreover to support farmers, the food industry and retailers can invest in renewable energy and equipment via subsidized loans (UNEP and UNDP 2021).

6.4.2 Cities and local governments

Cities will be home to two thirds of the world's population by 2050 and already approximately 70 per cent of all food produced worldwide is consumed inside cities (United Nations Department of Economic and Social Affairs 2019). City management can therefore play a key role in food systems transformation. Since 2015, city-to-city cooperation and best practices exchanges have been fostered by the Milan Urban Food Policy Pact, which includes 225 cities worldwide. In many cities, this has translated into revised public procurement policies (e.g. for public schools, canteens, hospitals, care centres and so on) to align them with healthy diet recommendations (FAO *et al.* 2020), to increase the share of organic products and/or from local suppliers and to reduce waste through directives, resolutions or orders, for example.

Moreover, integrating food production, access and distribution across urban planning must be considered as cities expand (FAO *et al.* 2020). Policies related to food systems inside cities also positively impact the creation of jobs related to producing, distributing, delivering, redistributing and recycling food.

Lastly, cities and local governments can serve as testing grounds for policies that could be scaled nationally and for innovative solutions, including those from start-ups.

6.4.3 Private sector

Business opportunities in implementing the SDGs related to food have been estimated to be around US$4.5 trillion out of the total food sector turnover of US$10 trillion per year by 2030, representing a huge opportunity for current businesses and for entrepreneurship in the sector (FOLU 2019). Given the investment opportunities in the food system, companies and their investors could pursue new opportunities, disruptive innovations and technology transfer in line with social and environmental goals.

New protein sources are a disruptive technology. In 2021, plant-based meat substitutes generated US$5 billion in sales, and forecasts suggest up to US$85 billion in 2030 (Thornton, Gurney-Smith and Wollenberg, forthcoming). Processing plant-based protein sources such as legumes into meat substitutes generate five times higher emissions than unprocessed plant-based sources, but remains 5–8 times lower than those from beef (Clune, Crossin and Verghese 2017; Rubio, Xiang and Kaplan 2020; Smetana *et al.* 2015). In contrast, lab-grown meat (sometimes referred to as cellular meat) currently has footprints that can be as high as those of beef (Smetana *et al.* 2015; World Economic Forum 2019).

Another important area to drive food system transformation, from a private sector perspective, includes sector- and company-wide targets to reduce emissions and eventually reach carbon neutrality (Burns *et al.* 2022). The Science-Based Targets initiative (SBTi) and other entities offer companies with target-setting methodologies based on the best scientific evidence and guidelines to track GHG emissions within the companies' operations. This initiative already comprises over 1,200 companies worldwide. A key aspect is enhanced transparency through systematic reporting and verification of company operations.

An example that openly accessible information can help drive action is the Big Climate Database developed in Denmark using life cycle assessments, which has already been used by several supermarket chains and the food service industry. Public disclosure of data used to measure progress and independent audits and initiatives, such as those of the World Benchmarking Alliance which ranks companies on their performance, will be important in assessing progress and increasing accountability.

6.4.4 Civil society (citizens and non-governmental organizations)

Citizens can drive food systems transformation through their consumption choices, their electoral choices and their mobilization in favour or against certain policy reforms related to food systems e.g. through boycott, public demonstration, disruption of traffic, etc. Social media has also played an important role in raising awareness on the need to shift diets and how to shift diets to reduce our carbon footprint. But this may only reach a certain audience e.g. with a higher education level (Eker *et al.* 2021).

An important voice for civil society initiatives are non-governmental organizations (NGOs). They often work closely with citizens and can represent a multitude of voices at local, national and international levels of governance. For example, the United Nations World Food Programme (WFP) works with over 1,000 NGOs worldwide to support 'close to citizen' activities and efforts.

Table 6.5 Potential solutions and barriers to food systems transformation by actor group

	MAJOR TRANSFORMATION GAPS	POTENTIAL SOLUTIONS	BARRIERS
National governments	– Absence of national strategy and clear measurable targets – Lack of data and capacity – Lack of key performance indicators to monitor progress – Weak evaluation of externalities and incorporation into national accounting	› Science-based national food systems transformation strategy and corresponding national coordination and accountability mechanism › Open government data › Integrate low carbon into national food and dietary guidelines › Strengthen national land monitoring system for carbon reduction	! Unbalanced power across ministries (and objectives) ! Lack of multisectoral coordination ! Acceptability of measures versus success at next elections
Cities and local governments	– Carbon reduction is not part of the local and city government mandate – Lack of awareness of carbon footprint of food systems	› Strengthen coordination between national and city governments/local plans and policies › Strengthen coordination between urban and rural areas › Align public procurement with healthy and sustainable diets	! Local economic development versus carbon reduction ! National versus local/city interests
Private sector	– Lack of commitments – Lack of capacity – Lobby against taxes and environmental regulations	› Monitor and disclose progress towards environmental commitments › Remove 'best before' label from fresh fruits and vegetables	! Economic profitability versus social and environmental objectives
Civil society	– Lack of knowledge and incentives – Small number of platforms which enable involvement in decision-making – Lack of resources (NGOs)	› Social campaigns and social movements › Mainstream low carbon into teaching curriculums › NGOs develop score cards for companies	! Budget constraints ! Well-being, cultural norms and preferences versus social and environmental goals
Academia	– Science not fully aligned with societal needs – Interdisciplinary approaches required but difficult to implement	› Build strong science-policy interface between governments and academia › Independent monitoring of progress towards targets related to food policy	! Disciplinary funding structures and research traditions ! Independence/separation of academia from policy processes

6.4.4 International cooperation

International cooperation is essential amid a strong interconnectedness of countries' food systems, large inequalities such as the impacts of climate change on food production and the complexity of climate change. While developments in food trade over the past decades have increased food availability and diversity, it has also increased the vulnerability of some countries' food systems to climate and political shocks (Wang and Dai 2021) and accelerated the destruction of natural ecosystems such as tropical forests (zu Ermgassen *et al.* 2020).

With strong interconnectedness, even well-intentioned national policies to reduce GHG emissions from food systems can be offset by spillovers to the rest of the world and/or could raise food prices but could also spur positive change in other countries. The negative impacts of climate change on agricultural production are also especially strong in developing countries. International cooperation to ensure that no one will be left behind is crucial. Channelling emergency food aid when there are crises, avoiding trade disruptions even when there is a war, or reducing food overconsumption can all contribute to reducing inequalities within global food systems.

Many technologies exist that are capable of increasing crop and livestock productivity, enhancing nutrition of food crops and reducing GHG emissions (Pathak and Aggarwal 2012;

Fan 2021; Islam 2021; Huang *et al.* 2022) but much needs to be done to scale up, adapt to local contexts and also ensure the equitable distribution of costs and benefits. International cooperations, including South-South cooperation, have a critical role in low-emission technology transfer and scaling.

As highlighted in this chapter, positive examples of reducing GHG emissions from food systems exist but they are scarce. International networks such as the Milan Urban Food Policy Pact for cities, the World Business Council for Sustainable Development for private companies, and the Food, Agriculture, Biodiversity, Land and Energy Consortium for scientists can help in sharing positive experience and peer learning across countries, fostering innovation. In the same vein, a global data and knowledge platform would be desirable to guide food systems transformation using science based recommendations (Singh *et al.* 2021). During COP 26 in Glasgow, various international key food systems-related activities were announced (box 6.3). These and similar initiatives carry the potential to unite actors internationally, (e.g. countries, international organizations, think tanks, development banks and more) to mobilize resources and capacity and pursue common goals.

Box 6.3 COP 26 initiatives that bear strong mitigative potential with regards to land and food systems emissions and the protection of natural ecosystems

The **Glasgow Leaders' Declaration on Forests and Land Use** reaffirms the critical role of forests "in enabling the world to meet its sustainable development goals" and the need to "reduce, halt, and reverse forest loss and land degradation by 2030". The Declaration has 141 signatory governments that together represent around 91 per cent of forested areas.

The **Forest, Agriculture and Commodity Trade Roadmap** aims to halt forest loss associated with agricultural commodity production and trade, joined by 28 countries and 12 companies so far that hold a considerable market share in forest commodities (that is, in soy, palm oil, cocoa and cattle).

The **High Ambition Coalition for Nature and People** includes nearly 100 countries that push for the ratification of ambitious post-2020 biodiversity targets at the upcoming Convention on Biological Diversity, such as placing 30 per cent of the territory under protection by 2030.

The **Global Methane Pledge**, currently signed by 122 countries, aims to reduce methane emissions by 30 per cent below 2020 levels.