CGIAR Initiative on *Rethinking Food Markets*

Initiative Technical Paper

Options for Reducing Greenhouse Gas Emissions from Agriculture and Food Systems

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Contents

Abstract

Food systems generate about one third of global greenhouse gas (GHG) emissions. Without reducing them, it will not be possible to stabilize the climate and keep the increase in global temperature below 1.5°C from pre-industrial levels. About 50 percent of agricultural emissions (in CO_2eq) comes from methane, a super potent GHG, mostly from livestock production and rice cultivation. We consider six broad approaches to emission reduction from agriculture—emission taxes, repurposing of farm subsidies, regulations, investing in green innovations, carbon credits, and demand-side interventions. We find that not only carbon taxes on agricultural production, but also rearranging agricultural subsidies will have only small impacts in terms of improving human and planetary health. Regulatory approaches, including conditionality and payment for environmental services (PES) can be counterproductive if they lower yields and require expansion of agricultural land use. Instead, we find that investing more in R&D for sustainable intensification of agriculture focused on productivity enhancing innovations have strong potential to generate major efficiency gains, drastic reductions in emissions and improved food security. Demand interventions designed to contribute both to environmental goals and improvements in health outcomes can play a supporting role. Since multiple sustainable development goals are to be achieved, no single instrument by itself will be effective. Instead, multiple policy instruments will need to be bundled and designed to create synergies and address trade-offs.

1. Introduction

Food systems generate about one third of global greenhouse gas (GHG) emissions. At the same time, agriculture and agrifood supply chains are highly vulnerable to the impacts of climate change. Without reducing emissions from agriculture, food production, and land use change it will not be possible to stabilize the climate and keep the increase in global temperature below 1.5°C from pre-industrial levels. Even if we managed to stop all other sources of emissions, global food consumption alone could account for nearly 1.0 °C rise in global temperature by the end of this century (Ivanovich et al. 2023). Soil degradation and deforestation caused by land use for agriculture have severely reduced nature's capacity to act as a sink for absorbing GHG emissions. About 50 percent of agricultural emissions (in CO_2eq) come from methane, a super potent GHG, much of it from livestock production and rice cultivation.

Global scenario analysis (Gautam et al. 2022) suggests that, without drastic policy change, emissions will continue to grow rapidly, with net emissions from agriculture and land-use change increasing by 200 percent between 2020 and 2040 and agricultural land use expands by 56 million hectares. Ready-to-use technologies and sustainable farming practices exist that are climate resilient and have great potential to reduce emissions and make progress towards other social goals (Barrett et al. 2020). Yet, such practices frequently have low adoption rates and lack adaptation to local contexts. Existing public support policies frequently provide the wrong incentives for adoption and fail to promote investment R&D for adaptation and packaging of 'green" innovations.

This paper reviews options for policy reform that would accelerate the adoption of sustainable practices and simultaneously pursue the objectives of climate protection and food security. Our review brings together three research elements: (a) a review of evidence on available sustainable technologies and practices and of how past policies have helped (or failed to help) promote the diffusion of breakthrough innovations in agriculture and food systems: (b) model-based scenario analysis to assess the potential of sustainable innovations and policies promoting these to reduce GHG emissions from food systems and achieve greater food security; and (c) a political-economy approach to understanding obstacles to policy reform.

Our review of evidence indicates that traditional approaches, such as regulations and carbon taxes, face challenges. Similar challenges are also apparent in proposals for reforming ('repurposing') the vast existing public support (over US$800 billion per year) provided by governments worldwide to farm sectors and consumers. We find that not only carbon taxes on agricultural production, but also rearranging agricultural subsidies to shift support towards production or consumption of low-emission agricultural commodity production have, at best, only very small impacts in terms of improving human and planetary health. Likewise, approaches that combine direct farm payments to adoption of organic farming practices (akin to payments for environmental services, PES) can be counterproductive if the environmental practices prove to lower yields and farm efficiency and increase demand for land and hence for land conversion and its associated emissions.

Instead, we find that investing more in R&D for sustainable intensification of agriculture focused on productivity enhancing innovations and their adaptation to local contexts have high potential to generate major efficiency gains, drastic reductions in emissions and improved food security. We conclude, therefore, that policy makers should consider combinations of policy interventions to create new technologies that reduce emissions and realign market incentives for the adoption and diffusion of climate resilient and emission reducing practices. This focus on the importance of developing new technologies likely parallels a key development in combatting non-agricultural emissions, with the rapid development of renewable energy and electric-powered transportation (Quiggin 2024).

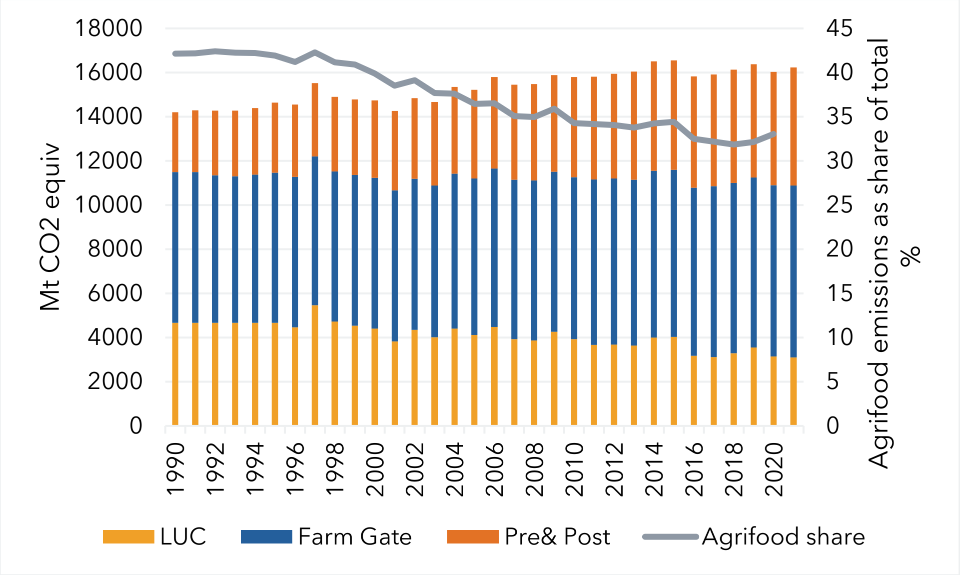
The remainder of this paper is organized as follows: section 2 describes the nature and magnitude of agrifood system GHG emissions; section 3 shows the medium- and long-term impacts of climate change on agricultural productivity; section 4 identifies ranges of new "breakthrough" technologies and practices that would help make food systems environmentally sustainable; section 5 assesses alternative policy approaches to promote adoption of sustainable technologies and practices and to induce shifts in food production and consumption that would lower GHG emissions; section 6 reviews existing evidence from model-based scenario analyses regarding the effectiveness of the alternative policy approaches to achieve both climate and food security objectives; and section 7 concludes.

2. The importance and nature of agrifood emissions

A critical issue for policy on the mitigation of GHG emissions from agriculture is the importance and nature of those emissions. If these emissions were sufficiently small, then perhaps there would be no need to focus on them as part of a general policy of reducing emissions. Another important question is the countries in which they are generated. If they are generated in just a few high-income countries, then perhaps policies for GHG emission reduction could focus on just those countries? A third key question involves the activities in which they are generated, and the specific GHG gases that are involved.

Figure 1 divides emissions from the agrifood sector into those from land use change (LUC), from production to farm gate, from the production of inputs and from the processing, marketing, and consumption of food. It shows that these three contributions to overall GHG emissions accounted for over 40 percent of global emissions from all sources in 1990 and still account for around a third of emissions in 2020. This makes clear that emissions from the agrifood system cannot be ignored if the world is to achieve the rapid and deep reductions in global GHG emission reductions needed to keep the rise in global temperatures manageable (IPCC 2023, p20; Ivanovich et al. 2023).

Figure 1. Emissions from the Agrifood Sector and their Contribution to GHG Emissions

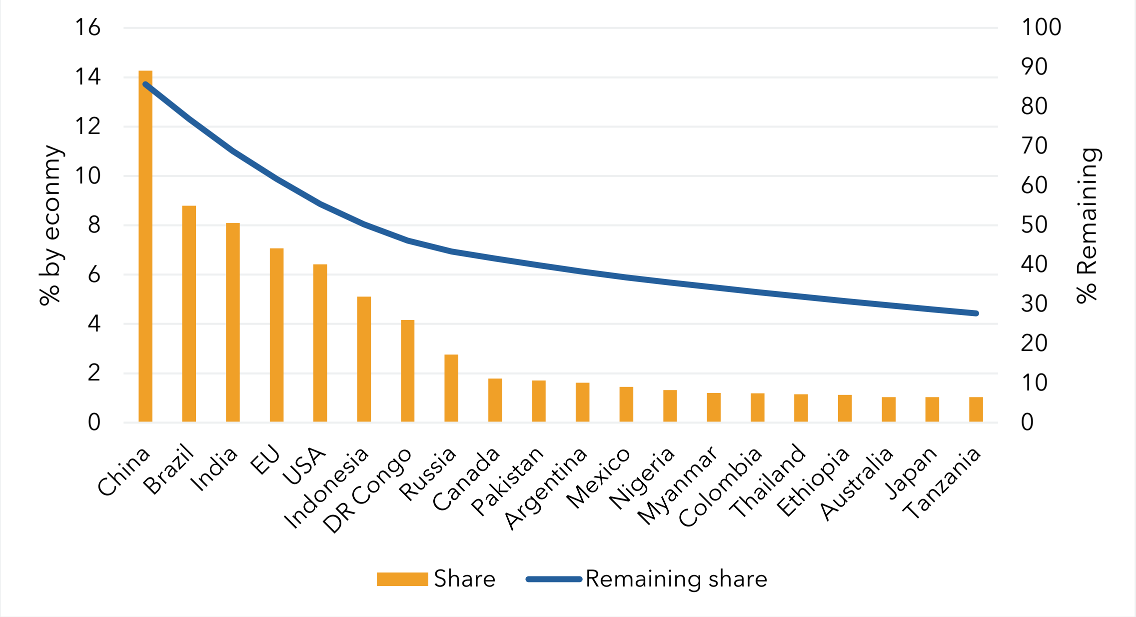


Sources: FAOSTAT (2024) for agrifood emissions and climatewatchdata.org for global emissions. Agrifood emissions exclude sequestration by forests. LUC emissions are those from changes in land use, such as clearing and burning forests to increase the area of pasture for cattle. Farm gate emissions are those from agricultural production, such as emissions from ruminant digestion. Pre and Post farm gate emissions are those from production of inputs such as fertilizer or from food processing, wholesale and retail trade.

This graph shows that total agrifood emissions have grown from 14.2 Gt/year in 1990 to 16.4 Gt/year in 2021, or at an average growth rate of 0.4 percent per year. This overall increase involved a substantial decline in emissions from land use change, which declined at 1.3 percent per year, together with gradual increases in farm gate emissions (0.4 percent per year) and rapid increases in pre- and post-production emissions (2.2 percent per year). The 23 percent of total emissions that arise from farmgate emissions and land use change pose both challenges and opportunities because they consist largely of decentralized process emissions for which carbon taxes are likely to of limited effectiveness. As we will see they provide opportunities for rapid reductions in emissions.

Another important question for policy making is from which countries agrifood emissions emanate. If a very large share of emissions comes from a reduced set of countries—ideally the industrial countries whose past development contributed most to the stock of GHGs—then mitigation efforts could focus on those few countries. Figure 2 shows the shares of the top 20 economies in global agrifood emissions, together with the share of emissions from the remaining countries. This graph shows that the top three emitters—China, India and Brazil— which are all developing countries, account for almost a third of agrifood emissions. The next two emitters—the United States and the European Union—account for 13 percent of emissions, slightly less than China alone. The remaining 15 of the top 20 emitters include a mix of developing and developed countries, including Indonesia, DR Congo, Russia, and Canada. The remaining 200 economies covered by the FAOSTAT database account for 28 percent of emissions—too large a share to ignore when the goal is to cut emissions very sharply.

Figure 2. Shares of Agrifood Emissions by Country (% of total agrifood GHG emissions)



Sources: FAOSTAT (2024) for agrifood emissions and climatewatchdata.org for global emissions. Agrifood emissions exclude sequestration by forests.

The data in Figure 2 have important implications for policy. Successful reduction in agrifood emissions must ensure that reductions occur in countries at drastically different income levels, from DR Congo to the United States, for example. Reductions in the largest emitting countries—China, Brazil, India the EU and the USA—are particularly important given that they account for around 45 percent of total emissions. However, because such a large share of emissions comes from countries outside the top 20, achieving reductions in emissions from a large range of other, relatively small countries remains important.

In addition, the nature of GHGs has important implications for the timing of successful reductions in global warming. The immediate global warming impact of methane emissions is around 120 times that of CO_2, while their 100-year impact is 27.8 times (US EPA Office 2023). This difference means that an immediate reduction in methane emissions has a much larger impact on global warming in the short run than a reduction in CO_2 emissions with the same 100-year impact[1]. Nitrous oxide (N_2O) emissions are, like methane, extremely potent and create additional harm by damaging the Earth's protective ozone layer.

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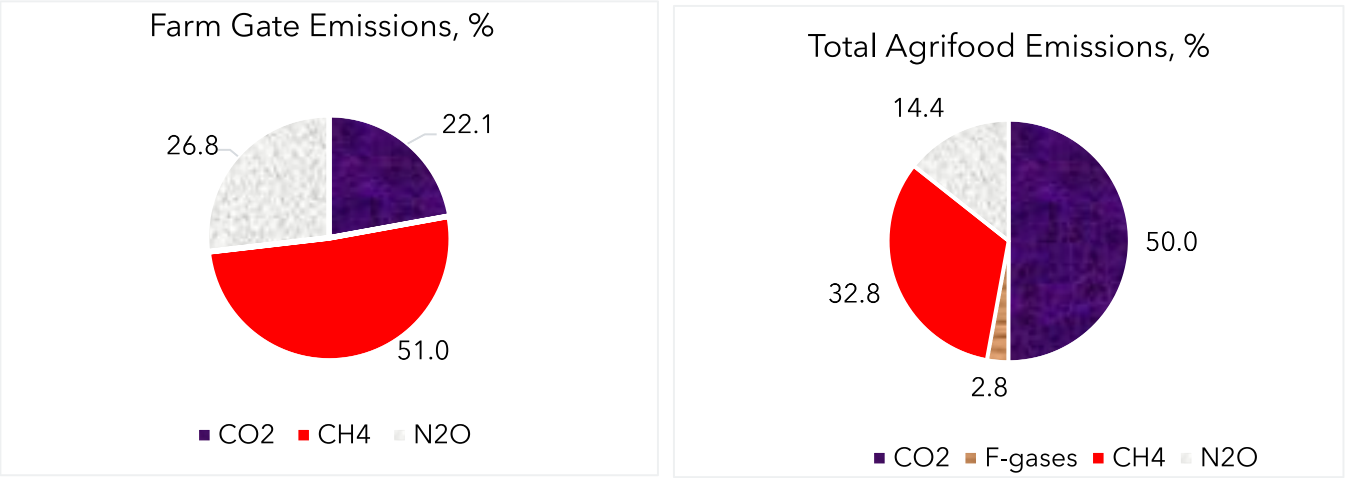
[1] IPCC measures the lifetime of GHGs by the time taken for their concentration to decline to 37 percent of its initial level. For Methane, this is 12 years; for N_2O, it is 110 years (IPCC 2007, FAQ 10.3), while a reliable lifetime for CO_2 cannot be defined because it is removed through different processes that happen at different speeds.

Figure 3. Agrifood Emissions by type of GHG gas in 2020, %

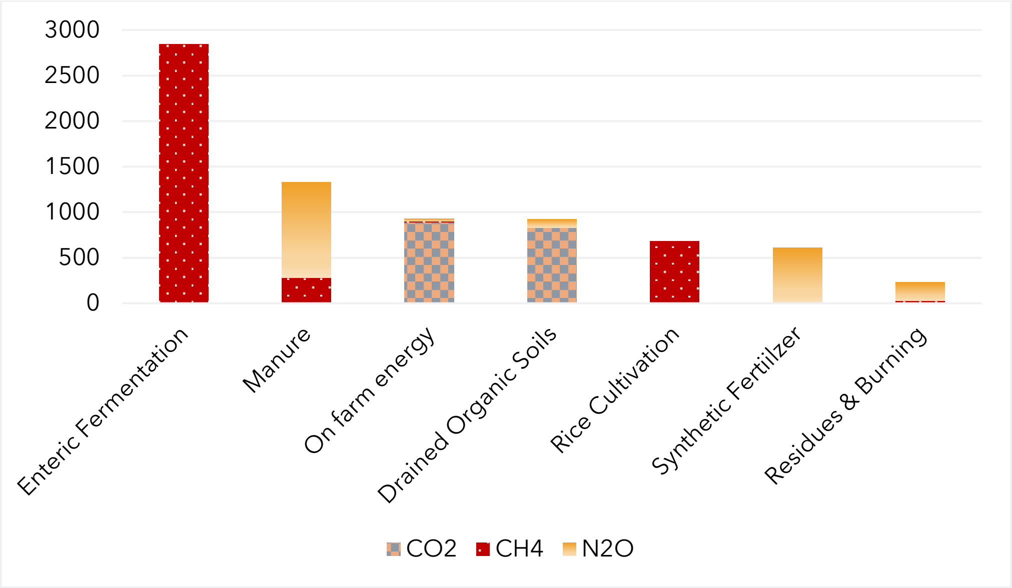


Sources: FAOSTAT (2024) for agrifood emissions and climatewatchdata.org for global emissions. Agrifood emissions exclude sequestration by forests.

A particularly striking difference in emissions by GHG gas is between farmgate emissions and total agrifood GHG emissions. Figure 3 shows the dramatically greater importance of CH_4 emissions within farmgate emissions relative to total emissions. While reducing carbon-dioxide emissions from combustion must clearly be the primary concern overall, reducing methane emissions is likely the highest priority in combatting farm-level emissions. Another major difference between farm-level and overall emissions is the much greater importance of N_2O emissions at the farm level. Like methane, these are also highly potent, although with much longer life in the atmosphere than methane, even if far less than CO_2.

The GHG composition of farm gate emissions differs very substantially between sources. Figure 4 shows emissions from seven major sources of farm emissions and their GHG composition. The largest source of emissions is enteric fermentation, which accounts for 38 percent of total farm emissions. Enteric fermentation generates almost exclusively methane emissions. The next most important source is emissions from manure, which make up 18 percent of the total and mostly generate N_2O emissions. The next two sources are on-farm energy use and emissions from drained organic soils, which predominantly take the form of CO_2 and account for almost 25 percent of the total. Emissions from rice cultivation come next at 9 percent of the total and almost entirely comprise methane. The final two main sources—synthetic fertilizers and residues and burning—predominantly generate nitrous oxides.

Figure 4. Contributions to Farmgate Emissions by Source and GHG, Mt CO_2 equivalent



Sources: FAOSTAT (2024) for agrifood emissions and climatewatchdata.org for global emissions. Agrifood emissions exclude sequestration by forests.

The N_2O emissions from agriculture—primarily from manure, synthetic fertilizers and crop residues— are particularly important because farmgate emissions contribute around 70 percent of total N_2O emissions. Further, these emissions are from manure and synthetic fertilizers, which tend to become much more important contributors to GHG emissions as incomes grow.

3. Impacts on agriculture and food systems

Global food production has expanded at a remarkable pace over the past 60 years. Per capita food production has grown by a factor of 3.8 between 1961 and 2021 (Martin & Vos 2024). A key driver of this expansion has been the diffusion of green revolution technologies for calorie-rich staple crops, especially cereals. High-yielding varieties developed by, among others, CGIAR (the international network of agrifood research centers) have contributed to the worldwide expansion of food production during this period (see e.g., Fuglie et al., 2020). The associated agricultural productivity growth has lowered staple food prices and has facilitated structural transformations of poor economies both helping reduce poverty and hunger worldwide (see e.g., Ivanic and Martin, 2018 and Gollin et al., 2021). While agricultural land use also expanded during this period, this expansion has been limited vis-à-vis production and population growth, reflecting a significant increase in land productivity, but also more intensive use of land resources.

Looking forward, global food demand is expected to grow by 50 percent (from 2015 levels) to 2050, considering expected population and income growth and the shifts in dietary patterns (FAO, 2017; Vos and Bellù, 2019). Using a measure of the resource demands created by the shift in consumer demand towards livestock products, Fukase and Martin (2020) estimate the increase in pressure on agricultural resources at closer to 100 percent. Moreover, a significant, additional demand pressure for agricultural produce is expected to be exerted by increased demand for biofuels.

Yet, given past trends, this would not seem an unsurmountable challenge. However, to say it with Yogi Berra: 'the future ain't what it used to be'. Growth in food production per capita is already showing signs of slowing down, having peaked in about 2010 (USDA, 2022; Gautam et al., 2022). The slowdown is strongest in developing countries. As shown in Figure 5, growth of agricultural output declined from almost 4 percent per year in the 1990s to barely 2 percent per year in the 2010s.

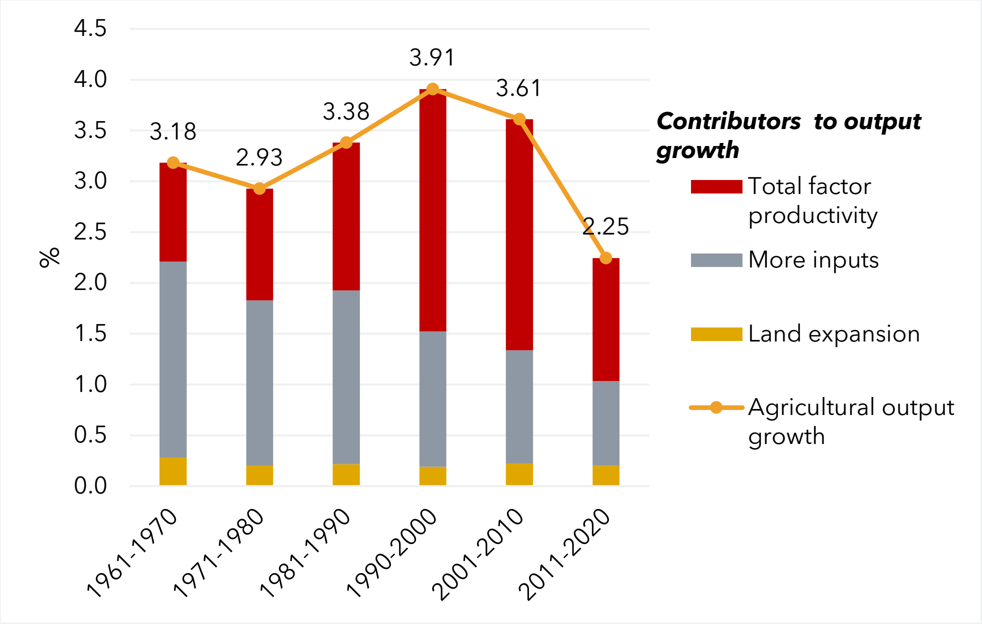
Importantly, food production worldwide will have to adjust to the threat of climate change and erosion of land, water, and other natural resources. The slowdown in agricultural productivity growth can be attributed in part to climate change. A recent study by Ortiz-Bobea et al. (2021) estimates that climate change has reduced global agricultural productivity growth by 21 percent since 1961, equivalent to losing roughly a decade's productivity growth. The impacts hit hardest on tropical agriculture, with productivity declines in some areas by 40 percent or more. A subsequent analysis by Thomas et al (2024) is slightly less pessimistic overall, but points to large declines in agricultural productivity both in high-income countries and in countries with very hot climates.

Nonetheless, long-term projections with IFPRI's IMPACT model (IFPRI, 2022, p142) suggest global per capita agricultural output will continue to rise to at least 2050, including after accounting for the adverse effects on yields of climate change. Unabated climate change would lower per capita agricultural production by 5-10 percent by 2050, in part, because agricultural production in template zones may still benefit initially from higher temperatures. Please note that these projections assume no impacts from extreme weather events.

Projections for per capita agricultural output in Sub-Saharan Africa are much more concerning. Even without climate change, per capita production is projected to fall from 2022 onwards, as yield growth is expected to be outpaced by population growth. By 2050, per capita production is expected to have fallen by 5 percent from current levels without climate change and this decline would have doubled to 10 percent in the scenario with climate change (Figure 6).

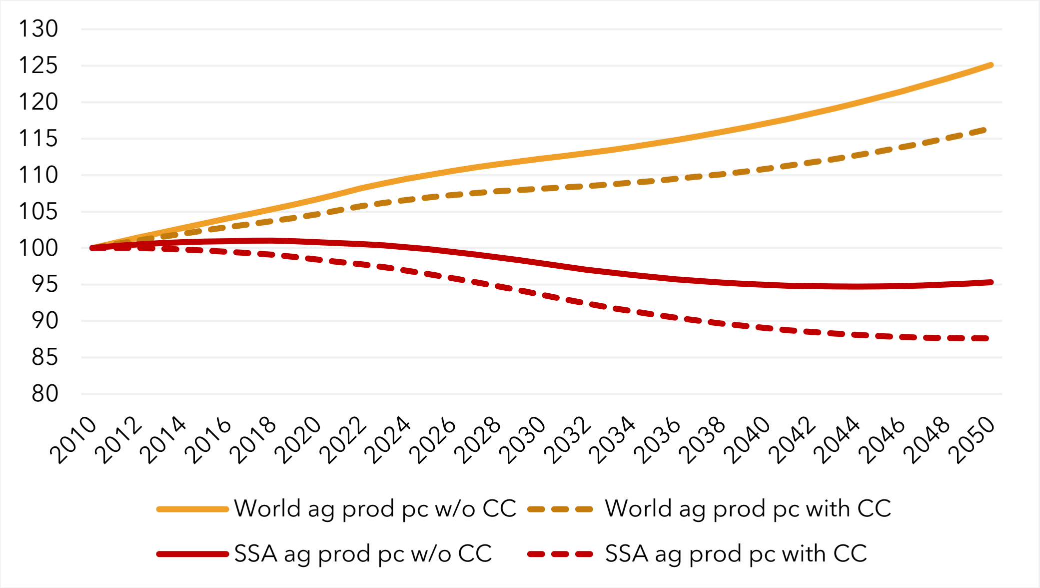
Climate change affects food availability through its increasingly adverse impacts on crop yields, fish stocks and animal health and productivity, especially in sub-Saharan Africa and South Asia, where most of today's poor and food insecure live. It limits access to food through negative impacts on rural incomes and livelihoods. Poor people, including many smallholder farmers and agricultural workers, also tend to be more vulnerable to the impacts of extreme events. Intensified and more frequent occurrence of droughts and floods will sharply reduce incomes and cause asset losses that erode future income earning capacity of those affected. In addition, to the extent that food supply is reduced by climate change, food prices will increase. Both urban and rural poor would be disproportionally affected, as they spend much higher shares of their income on food.

Figure 5 Agricultural Output in Developing Countries slowed in the 2010s



Source: Estimates based on USDA, Economic Research Service (ERS) International Agricultural Productivity data product (https://www.ers.usda.gov/data-products/international-agricultural-productivity/)

Figure 6: Lower per capita agricultural production because of climate change, 2010-2050



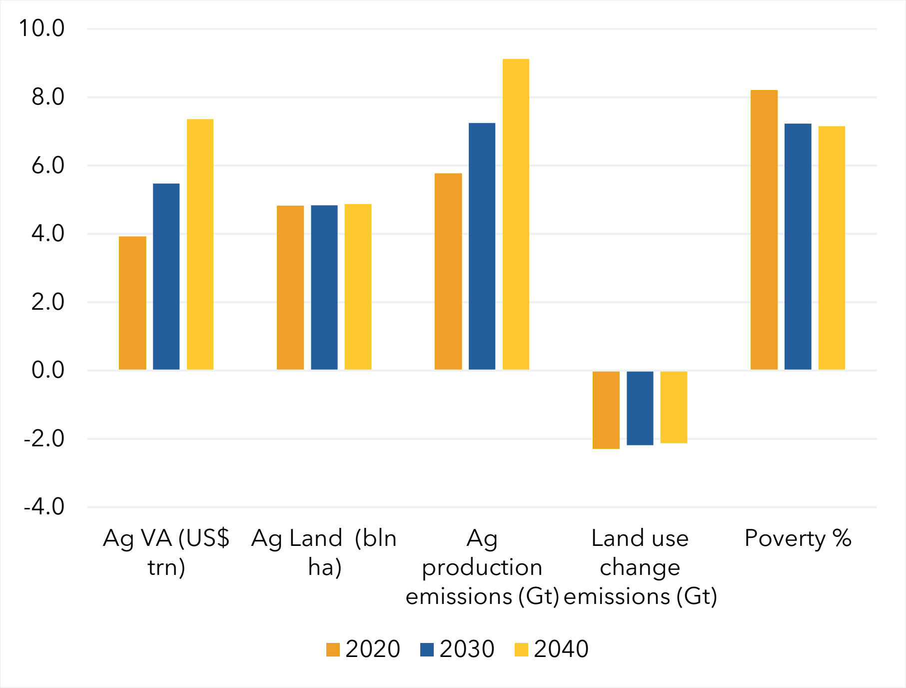
Source: Projections based on IFPRI's IMPACT model (see IFPRI 2022) and UN Population Division for Population Projections (medium variant). We used grafted polynomials (Fuller 1969) to generate a projection path with a continuous slope.

Given that managing the challenges of global warming will take sustained effort over an extended period, a key question is how the agricultural sector, and emissions from agriculture will evolve. To examine this question, we turn to projections prepared for a recent IFPRI-World Bank report (Gautam et al. 2022). This study examined the evolution of the world economy, and agricultural output and emissions, to 2040. Key outcomes relevant to the agriculture sector are shown in Figure 7. Real agricultural value added in US$ of 2017 would increase by 88 percent, from US$3.92 trillion to US$7.36 trillion. This growth would be underpinned by an increase of 87 percent in crop production and 48 percent livestock production between 2020 and 2040.

Global poverty headcount rates would fall from 8.2 percent to 7.2 percent. This slow rate of decline in poverty is strongly influenced by the relatively low rate of growth in agricultural productivity in low-income countries (Ivanic and Martin 2018). Agricultural land use would expand by 23 million ha between 2020 and 2030 and further by 33 million ha to 2040, implying an increase in agricultural land use by 1.2 percent between 2020 and 2040.

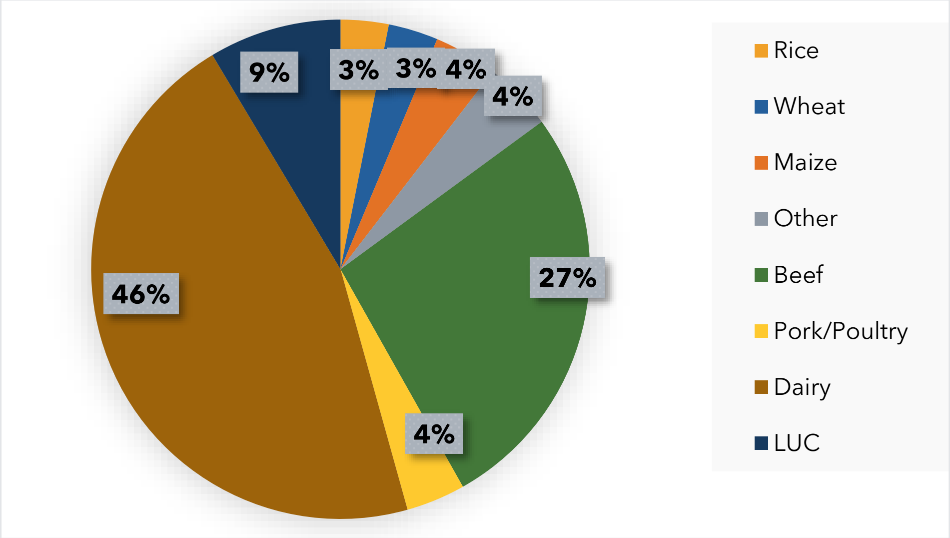
The baseline scenario further projects a significant increase in GHG emissions from production, rising from 5.8 Gt of CO_2 equivalent to 9.12 Gt, a 58 percent increase (Figure 8). Net annualized emissions from land use and land use change are negative with emissions from land use change outweighed by sequestration in forests and other sinks. However, these are far outweighed by rising emissions from agricultural production.

Figure 7 Key Features of Baseline Projections



Source: Gautam et al. (2022). Baseline projections using IFPRI's MIRAGRODEP model.

Figure 8: Projected Sources of Growth in GHG Emissions from Agriculture and Agricultural Land Use Change, 2020-2040 (%)



Source: Gautam et al. (2022). Baseline projections using IFPRI's MIRAGRODEP model.

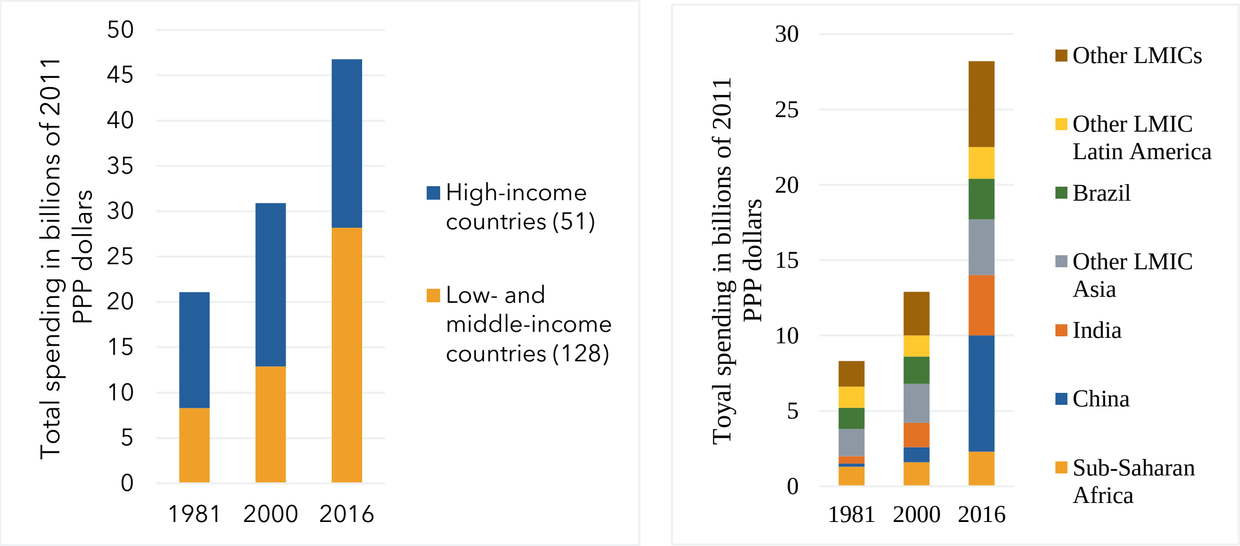
As shown in Figure 8, the largest increases in emissions would be from livestock production (84 percent of incremental emissions from agricultural production, dominated by enteric fermentation contributing 65 percent of incremental livestock emissions and 54 percent of all agricultural production emissions). Significant increases are also expected in emissions from crop production (part of which reflects increased demand for livestock feed) (Figure 8). The primary contributor to incremental crop production emissions is expected to be synthetic fertilizers (55 percent of crop emissions and 9 percent of all total production emissions).

At the core of finding viable solutions to the enormous challenge of making agriculture more productive, sustainable, and nutrition-sensitive are improved technologies and practices as much as market incentives for both adoption of improved practices and shifting consumer demand. In other words, do current agricultural support policies create the right incentives for producers to make appropriate decisions for achieving the desired goals? We turn to these issues in Sections 4 and 5.

4. Can the threat of climate change be averted?

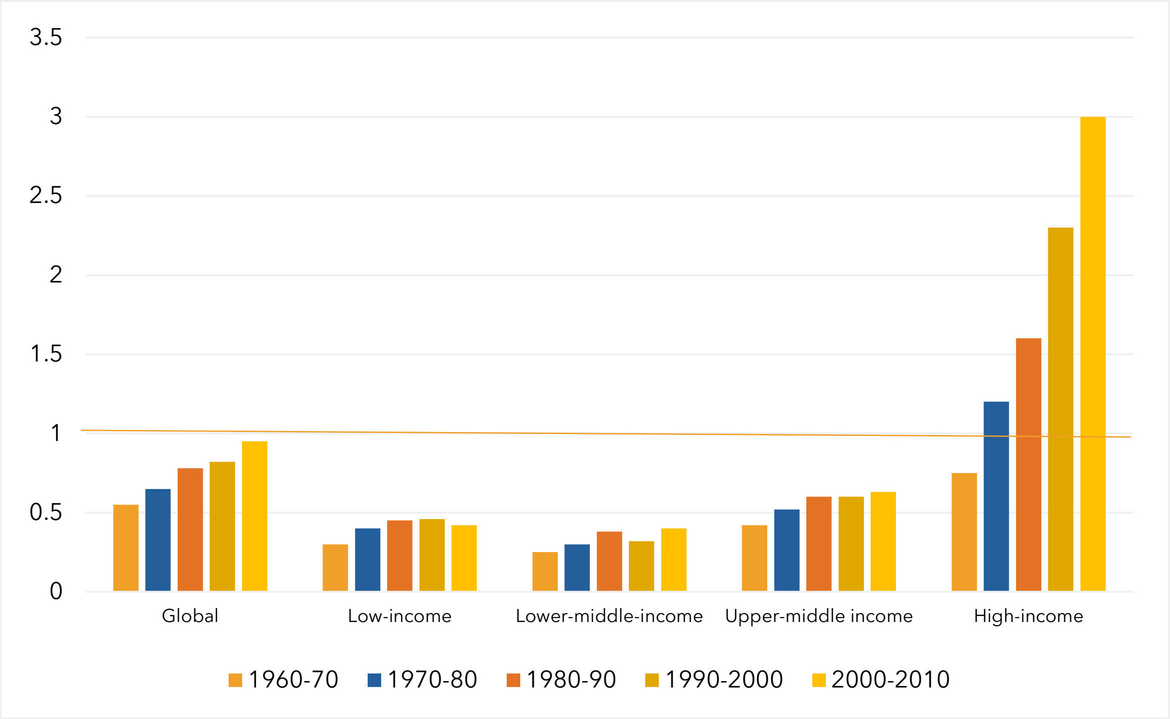
A main reason why accelerating agricultural productivity is challenging is underinvestment in agricultural R&D in recent decades. Levels of R&D spending have increased in recent decades, with much of growth coming from a few developing countries, especially from Brazil, China, and India (Figure 9). Nonetheless, current levels of R&D expenditures are too low for comfort, especially for agricultural development in low-income countries. A commonly used indicator of countries' relative agricultural research efforts is the agricultural research intensity index (ARI), which expresses national expenditure on public agricultural R&D as a share of agricultural GDP. Clearly, low-income countries lag far behind high-income countries and are increasingly losing ground (Figure 9). While it is hard to define the 'adequate' level of ARI, overall government R&D expenditure for science and technology of at least 1 percent of national GDP has been recommended (FAO, 2017). For the agriculture sector, countries in both the low-income and the lower middle-income groups are generally well below this threshold (Figure 10).

Figure 9 Agricultural research spending by income groups and selected countries, 1981-2016



Source: Beintema, Nin Pratt and Stadts (2020) ASTI GlobalUpdate. https://ebrary.ifpri.org/digital/api/collection/p15738coll2/id/134029/download .

Figure 10 Averages of agricultural research intensity, by country income group, 1960-2010



Source: Pardey et al. 2014.

Note: Simple average of annual agricultural research intensity (ARI), measured as the ratio of public expenditure on agricultural R&D to agricultural GDP.

Furthermore, Beintema et al (2020), based on IFPRI's database of Agricultural Science and Technology Indicators (ASTI), estimate the global gap for agricultural R&D investment at 34 percent. The Commission on Sustainable Agriculture Intensification (CoSAI) focused on the gap in investments for R&D for technologies and practices for sustainable intensification. It estimates this R&D investment gap at US$15 billion per year to be allocated towards innovations for sustainable intensification tailored to production conditions in LMICs. (CoSAI, 2021). Meanwhile, private investment in R&D has increased, currently contributing an estimated 20 percent of total agricultural R&D expenditures (FAO, 2017; 2022).

However, the hurdles to adoption of these new technologies can be formidable (see, for example, Liu 2018). Even if policy makers and policy advocates feel confident that adoption of a particular technology will reduce costs, raise productivity, and increase resilience, uncertainty remains about the productivity impact of that technology in any specific environment. For instance, certain innovations may need additional inputs, like – as mentioned – in the case of Green Revolution technologies which boosted productivity where farmers could access fertilizer, irrigation, and adequate market infrastructure, such as in Asia, while it did not in Africa, where such complementary inputs were often difficult to access or simply unavailable. Similarly, sustainably produced foods may meet consumer resistance, for instance, if produce labelled as, say, "organic" come at a higher price or consumers consider it inferior to produce that is not. As a result, the technology cannot be brought to scale because of limited demand. Given this, any policy that encourages or requires adoption of climate-resilient technologies must recognize the risk that producers perceive these may not improve productivity enough compared with the cost of adopting these.

The increasing involvement of the private sector and the use of proprietary technologies in the face of continued widespread poverty and climate change reinforces the importance of regulation and the strengthening of public good providers such as the CGIAR system and regional and national agricultural research systems.

Importantly, also, new technologies not only need to significantly improve productivity but make sure these substantially lower emissions and underpin sustainable intensification in agriculture and low-emission energy use in post-harvest food sector activity.

A mix of emergent circular feed, controlled environment agriculture, precision fermentation, and cellular tissue engineering technologies can dramatically reduce the terrestrial and marine footprint of farming, especially in producing higher-value foods and high-quality diets. The production costs of these methods are falling fast, making them increasingly viable. Orderly substitution of capital for land in food production will require cross-sectoral coordination; creation of eco-payment systems rewarding landowners for biodiversity conservation, carbon sequestration and other ecosystem services; shifting from production-based agricultural subsidies to incentives for rural investment in renewable energy; and implement robust safety nets for those disrupted and marginalized by inevitable transitions.

It will also require raising awareness among consumers and tap their latent valuation of more sustainable and healthy foods to incentivize beneficial innovation and technology adoption. Public policies can help raise such awareness. Policies will also be needed to steer change by providing tangible incentives to both consumers and producers through taxes (on high-emission or unhealthy foods), subsidies (on low-emission and healthy foods), adequate food labelling and certification, and compensatory schemes for producers to overcome the cost of switching to sustainable practices or to low-income consumers facing greater difficulties to access nutrient-rich foods. A good starting point will be to rethink current agricultural support policies and assess the potential for repurposing resources for more R&D and incentive schemes that would promote food security and healthy diets through sustainable production. We now turn to this question.

5. Policy approaches to climate change mitigation and adaptation in agriculture

The Paris Agreement (UN 2015) provides for countries to declare Nationally Determined Contributions (NDCs) that seek to use peer pressure to overcome the collective action problems associated with global emission reductions. For this policy to be effective, countries must adopt policies that create incentives to change the way products are produced or consumed.

Five broad policy approaches to reducing emissions from agrifood can be identified: (i) carbon tax-based approaches, (ii) repurposing or elimination of agricultural support (iii) regulatory approaches, (iv) carbon credits, (v) innovation-based approaches, and (vi) interventions designed to change food demand. Each of these approaches needs to be evaluated against multiple criteria, including: (i) the cost per unit of emission reduction, (ii) the extent to which they encourage agents to identify the most economical ways to reduce emissions, (iii) their impacts on emissions from both agricultural production and land use/land use change, (iv) their complementarity with other approaches, (v) their potential sensitivity to rebound effects, (vi) whether they are vulnerable to leakage if applied in only one country, and (vii) short- and long-term implications for other goals such as increasing economic growth in poor countries and reducing poverty and food insecurity. We first consider the broad features of each of these types of intervention, before turning to the available evidence on their potential effectiveness in the next section.

5.1 Emission Taxes

Economists have identified many reasons to favor the use of carbon taxes (or related measures such as transferable emission quotas) to mitigate emissions from combustion. In this context, it is easy to measure and tax CO2 emissions because they are produced in roughly fixed proportions with the amount of fuel burned. Carbon taxes can simply be set based on the CO2 intensity of individual fuels, without needing to monitor actual emissions from individual, decentralized activities. Tradeable quotas for emissions from combustion have similar properties by creating a price for emissions and providing the same incentives to reduce emissions to all covered producers and consumers.

A key advantage of carbon taxes over regulatory approaches in this context is that they provide decentralized economic agents with incentives to identify ways to reduce emissions in the lowest cost manner. Putting a price on carbon creates three broad types of incentives to reduce emissions: (i) incentives to change production techniques to reduce emissions at any given level of output, (ii) incentives to reduce the output of emission-intensive goods, and (iii) incentives for research and development (R&D) intended to reduce emissions. Considering transport, for example, fuel consumption can be reduced by changing to more fuel-efficient vehicles, by reducing the amount of cargo carried, or by investing in designing and building more efficient vehicles. The carbon tax provides incentives to reduce emissions at all these margins. As long as the carbon tax is equal across agents, they will have the same incentive to reduce emissions, leading to efficient choice of approaches to emission reduction.

As noted by Acemoglu et al. (2012), carbon taxes and incentives to invest in emission-reducing technologies are potentially strongly synergistic. The carbon tax creates incentives for producers to demand lower-carbon production technologies, while the innovations resulting from the investment incentives reduce the magnitude of the carbon tax needed to achieve any emission reduction.

Unfortunately, relative to their effectiveness in reducing emissions from combustion, carbon taxes are less suited to reducing emissions from farm-level agriculture and from land use and land use change. As we have seen, these are largely decentralized process emissions, such as those from enteric fermentation by ruminants, from organic soils, from manure, or from volatilization of synthetic fertilizers. Only 12 percent of on-farm emissions consist of CO2 emissions from fuels used on farm. While it might be possible to use a carbon tax based on N2O emissions to discourage use of synthetic fertilizers, the link between fertilizer use and these emissions is much weaker than with hydrocarbon fuels. For most of the other process-based emissions from agriculture or land use change, monitoring and taxing emissions from these decentralized processes is likely to prove extremely challenging. Without the ability to monitor actual emissions, a carbon tax on meat or dairy products would operate only through the output channel.

To the extent that it is possible to reduce agricultural emissions with a carbon tax, the tax would reduce both emissions from production and from land use and land use change. Output cuts associated with imposition of carbon taxes would reduce the land needed for agriculture, thereby reducing pressure to convert land into agriculture, and increasing the amount of forest land available to contribute by sequestering CO2. If full border tax adjustments are added to a carbon tax, the incentives to change to lower-emission technologies remain, while the output effect operates through product demand, which is likely less subject to leakage than production (Martin 2023). A carbon tariff, such as that proposed by the EU, shifts the burden of the tax from production to consumption for imported goods only, while imposing a double burden on exports—first from the carbon tax on production and second through the increase in costs associated with the carbon import levies on importables. Such a tax creates large-scale distortions of all relative prices in the economy, gross economic inefficiencies and potential export collapses.

The potential problem of leakage, where emission reductions in one country are undercut by increases in emissions from other countries has received a great deal of attention in discussions of carbon taxes and other measures subject to this problem, like regulatory approaches. Dumortier and Verma (2021) analyse the effect of a US carbon tax applied only to fuel use in agriculture. Their results suggest that leakage between countries as exports decline and imports increase in countries imposing a carbon tax is a serious problem. This may in principle be reduced using a carbon border tax adjustment, as noted in Martin (2023). It also becomes less serious as the set of countries subject to the tax increases.

Emission taxes may have potentially serious distributional consequences. A tax on rice production, for example, might impose serious burdens on poor rice producers. Carbon taxes on a large share of rice production or imposed as a tax on demand using a carbon border adjustment mechanism (CBAM) would raise the consumer cost of rice which is a key staple in many poor countries. Carbon taxes applied on a large scale would raise food prices, which could put people’s access to food at risk. While the revenues from carbon taxes could potentially be used to compensating losers, this would likely be challenging since it would involve a need to compensate small producers for the adverse impacts on their income and consumers for the effects on food prices, which would depend on the actions of all countries, making it challenging to identify.

5.2 Repurposing or Eliminating Existing Agricultural Support

Considerable attention has been focussed on the repurposing or removal of agricultural support. A widely popular view is that much support is focused on emission-intensive commodities and that eliminating or rearranging this support might sharply reduce emissions. Most attention focuses on budgetary support because this support unambiguously increases farm output and, with given technology, emissions from agriculture (Mamun, Martin and Tokgoz 2021). By contrast, reductions in market price support have little or no overall impact on global emissions because, while they increase output in protected regions, they reduce it elsewhere and raise the average consumer price of food.

Eliminating market price support certainly helps to reduce production in higher-cost regions although these may or may not have higher emission intensities. Mamun, Martin and Tokgoz (2021) note that some of the highest rates of market price support are provided in high-income countries, where emission intensities are generally lower than in developing countries, although these intensities have been falling more rapidly in developing countries.

The aggregate impact of subsidies is to increase food output with any given technology, so they increase the agricultural land footprint and so contribute to deforestation and emissions from land use change and erode the long-run sequestration biodiversity benefits associated with leaving land in nature. Elimination of agricultural subsidies can be complementary with other approaches that require budgetary resources. One example is the repurposing of agricultural support into research on green innovations that both raise efficiency and reduce emission intensities (see Gautam et al. 2022).

Elimination of subsidies does not face the rebound problem characteristic of innovations that raise productivity and lower output prices. However, subsidy reduction does face potential leakage problems. If only one country or group of countries reduces subsidies, then the consequent reduction in output and emissions in those countries could be partially offset by higher world prices and output increases in the rest of the world. This problem is more serious when subsidies are cut on only a small percentage of production. As the share of output subject to subsidy reduction is increased, the costs of relocating production increase, just as they do when a larger share of production becomes subject to a carbon tax (Henderson and Verma 2021).

A potentially serious problem with subsidy rearrangement or reduction—other than the associated political challenges of implementation— is undesired impacts on poverty and food insecurity. Removing subsidies will tend to raise world food prices, likely making it more difficult for poor consumers to access food. This problem likely also arises with subsidy rearrangements that, for instance, transfer support to staple foods like rice that are heavily consumed by poor people to healthier products like vegetables. Carefully designed repurposing that takes these concerns into account can still make progress as long as the complementarities and/or trade-offs between instruments are considered.

Repurposing of agricultural support remains important because of the vast scale of the resources devoted to it and the need to make progress on a wide range of social goals. Detailed analysis reported in Gautam et al. (2022) concludes that the potential for gain towards a wide range of objectives is greatest with approaches that allocate a portion of the current spending to investments in developing new technologies that both reduce emission intensities and increase productivity. Given the high rates of return to other investments in agricultural research and development (Alston, Pardey and Rao 2020) there is, of course, a strong case for increasing investments in agricultural research and development beyond current levels.

5.3 Regulatory Approaches

Regulatory approaches include direct imposition of regulations, payments for environmental services (PES), and other conditional payments to farmers. These approaches are considered part of options for repurposing of existing agricultural support, being less market distorting. They share a key common feature, although they are frequently considered separately. In particular, the action(s) to be taken to mitigate emissions is identified by the scheme administrator, rather than being identified by individual agents. Under the pure regulatory approach, the action to be taken is simply required, subject to penalties for non-compliance. Under PES, agents are rewarded for taking the identified action. Under "conditionality", failing to take the required action is punished by removal of benefits, such as those provided by government support.

A major challenge with these approaches is difficulties in identifying the best approaches to emission reduction. Typically, this will result in some low-cost approaches to emission reduction being missed and some very high-cost approaches to emission reduction being undertaken. Another challenge is that the incentive for further reduction in emissions drops to zero once a compliance level has been achieved. One case where regulatory and incentive-based approaches have been extensively compared is the US Acid Rain program designed to reduce emissions of SO2 from generation of electricity using coal. Chan et al. (2018) found the costs of reducing emissions under this program to be about 20 percent lower than would have been the case under uniform reductions in emissions brought about by regulatory approaches.

Another inherent problem of the regulatory approach is the need for monitoring and ensuring compliance. Since producers typically do not want to use the approach required by regulators, they have an incentive to avoid doing so. Ensuring that they do requires monitoring to ensure that they have followed the required approach and compliance measures to punish violations of the requirements.

Another problem with regulatory approaches relative to alternative approaches to emission reduction is specific to agriculture. To the extent that regulatory approaches require producers to use currently available technologies that they would not otherwise have chosen, it is highly likely that these technologies involve lower productivity at current prices than the technologies that they would have chosen. Moving towards organic agriculture, as proposed under current EU plans (European Commission 2020), seems likely to involve a reduction in yields of around 20 percent (Ponisio et al. 2014). Reductions in fertilizer use are likely to have even larger impacts. Given generally low elasticities of demand for food, these reductions in productivity are likely to create pressure to bring additional land into agriculture, creating emissions from land use change and reducing the forest area available for sequestration of emissions in the future.

Regulatory approaches potentially suffer from a similar problem of leakage as with carbon taxes. If one country or group of countries, uses regulations to reduce emissions, their cost competitiveness will be reduced and some of their output is likely to be replaced by suppliers from other countries—either by increased competition in domestic markets or in export markets served by the regulating country.

Regulatory approaches that impose requirements may also create poverty and food insecurity problems if they reduce the incomes of producers. PES or conditionality-based approaches have less risk of doing this from the producer side. If imposed on a large scale, however, they do raise prices and could create poverty problems among net buyers of food through higher food costs.

5.4 Credits for emission reductions

Credits for emission reductions or avoided emissions involve payment from one party to a second party for the second party to take actions that reduce emissions. Under the Kyoto Protocol, one group of mostly rich countries was required to reduce emissions, while another group of mostly-developing countries were not required to do so. The Clean Development Mechanism (CDM) under the Kyoto Protocol (Larson et al. 2011) was introduced with both efficiency and equity goals. Because emission intensities of production are frequently higher in developing countries, it is likely that the marginal costs of abatement would be lower in developing than in developed countries. Payments from rich to poor countries to undertake abatement activities would contribute to equity goals. Under this scheme, the reductions in emissions achieved under these agreed projects counted towards the industrial countries' achievements. Similar arrangements to the CDM have been developed under Article 6 of the Paris Agreement. Broadly similar arrangements have applied on a voluntary basis for reduced carbon emissions from deforestation and forest degradation, known as REDD+ (West et al. 2024). Surprisingly, nothing in the Paris Agreement prevents both the paying country and the host country counting the resulting emission reductions in full against their committed national emission reductions (Pande 2024).

The emission intensity data presented in Table 1 make clear that emission intensities in the major sources of emissions (beef and milk) from agricultural production are considerably higher in countries outside the OECD group of relatively rich countries. A large contributing factor to these higher emissions is lower productivity with, for example, lower milk yields per cow and slower weight gains in cattle requiring the maintenance of larger herds for any given level of beef production. In this situation, developing countries have more options for reducing emissions than high-income countries that are generally closer to the production possibility frontier. In this situation, marginal abatement costs are likely to be lower in developing than in developed countries. Busch and Engelmann (2017) conclude that reducing emissions from tropical deforestation is also a potentially very low-cost way to reduce global emissions.

Like carbon taxes, and unlike direct regulatory approaches, carbon credits allow promoters of credit-based schemes to identify what they see as the most cost-effective approaches to reducing emissions. However, these promoters likely do not know of the most cost-effective approaches to reducing emissions as well as the producers or consumers that actually generate emissions. Another major challenge with credit-based approaches is the need to define a baseline for emissions that would otherwise have occurred. The hypothetical nature of this baseline presents both analytical challenges and opportunities for abuse. If, for instance, the baseline used for a project is the levels prevailing at the beginning of the project, there is a risk that autonomous changes would, in any event, bring about reduced emissions without the policy having any impact. In this case the payments would be paying for reductions in emissions that would have occurred in any event.

Table 1 Average Emission Intensity and Agricultural Emissions Shares (%) by Commodity and Country Grouping, 2021

	OECD		**Non-OECD**		**World**	
	Intensity	Share (%)	Intensity	Share (%)	Intensity	Share (%)
Ruminant Meat	17.5	52.6	36.1	52.4	29.7	52.5
Milk	0.6	20.3	1.4	18.1	1.1	18.5
Rice	1.2	3.2	1.0	18.7	1.0	15.6
Cereals, excl. rice	0.2	13.6	0.2	5.9	0.2	7.5
Pigmeat	1.9	8.0	1.5	2.7	1.7	3.8
Poultry	0.3	1.1	0.7	1.3	0.5	1.2
Eggs	0.5	1.1	0.6	0.9	0.6	0.9
		100.0		100.0		100.0

Source: FAOSTAT

Calel et al. (2025) point out a serious problem with the operation of the baseline under the CDM. Under this scheme, the reductions in emissions associated with adoption of emission-reducing technologies are counted and made available as credits that that are then purchased by enterprises that would otherwise have been obliged to reduce their omissions. The problem is that only some of the reductions in emissions counted under the CDM are net reductions in emissions, while others are inframarginal reductions that would have occurred in the absence of the scheme. Calel et al. (2025) estimate that the majority of approved CDM carbon offsets were allocated to projects that would likely to have been built anyway. They conclude that sale of these offsets to regulated polluters may have resulted in substantially higher global carbon dioxide emissions.

In addition, there is a risk that the benefits of projects will be fraudulently overstated. West et al. (2023) conclude that the benefits of REDD+ projects have been massively overstated. Pande (2024) concludes that carbon credits are currently working poorly and points to a range of potential reforms that might turn voluntary carbon credits into a more effective approach to reducing global emissions—essentially by replicating the operation of a cap-and-trade mechanism or a carbon tax.

5.5 Innovation-based approaches

The gold standard approach to reducing emissions in agriculture is probably green innovations that both reduce emission intensities in production and raise efficiency. Raising economic efficiency, and particularly yields, has a strong advantage in agriculture because it reduces the need for agricultural land, thereby reducing emissions from conversion of land into agriculture and increases the amount of non-agricultural land that can potentially contribute to sequestration of emissions. Increasing economic efficiency on its own is not enough, however, because of the rebound effect whereby improvements in efficiency lower the cost of the good and increase the quantity demanded.

Ideal innovations for climate change mitigation are transformational ones that sharply reduce emission intensities. Incremental improvements in efficiency will, if the elasticity of demand is high enough, may actually end up increasing demand for dirty goods and even increasing emissions—as in the case of improvements in steam engines leading to greater demand for coal considered by Jevons (1865).

Combining improvements in efficiency with reductions in costs is particularly important in agriculture for two reasons. The first is that efficiency improvements create incentives for producers to adopt these innovations, reducing the need for adoption mandates and for monitoring. A second is that such improvements overcome the problem of international leakage. If one country/region adopts an innovation with lower emission intensities and higher productivity, the resulting decline in the world price will cause producers elsewhere to reduce their output, thereby eliminating leakage.

There are good reasons to expect that improvements in efficiency and reductions in emission intensity can be combined in agriculture because the most important of these emissions represent are gratuitously wasteful. The challenge of reducing methane emissions from ruminants and from rice is essentially to convert these emissions from a damaging pollutant into useful products.

Two remaining concerns are the potentially long time needed for adoption of innovations and that the incentives emanating from existing farm support may work against adoption. First, how long this takes depends heavily on the extent and clarity of the gains from adoption and whether they are equally available to small and large producers. Ruttan (1977) points to the staggeringly rapid adoption of green-revolution cereals in Asia during the 1960s—with, for example, improved varieties of wheat leaping from 3.6 percent of the Indian Punjab in 1966/67 to 66 percent in 1969/70. For many innovations and in many other locations, however, the adoption process can take longer, particularly if an innovation requires substantial capital investment, or is conditional on the availability of irrigation (Feder, Just and Zilberman 1985). The long timescales involved in past energy transitions, such as the replacement of coal and biomass by oil and gas in the late 20th century give rise to concern about the speed at which a full transition to renewables might occur (UN 2009, p47) although Quiggin (2024) is much more optimistic about the speed of the energy transition following recent, rapid declines in the cost of energy from photovoltaic cells. Second, existing longstanding farm support tends to promote unsustainable practices (e.g., Laborde et al. 2021; Gautam et al. 2022) and, hence, investing in green innovations will need to be combined with a realignment of incentives promoting their adoption and adaptation to local conditions.

Green innovations may take many forms. There is a growing portfolio of food system innovations that could accelerate change towards sustainable food system transformation. These include numerous digital innovations, such as precision agriculture, robotics, and applications for e-commerce, e-procurement, e-payment systems, and product quality traceability, as well as a wide array of other innovations such as genomics for development of climate-resilient crop and breeding varieties, process-synthesis approaches to plant-based protein-rich foods, biodegradable coatings for fruits and vegetables, and new drying methods (see e.g., Barrett et al., 2020; Herrero et al., 2020; Reardon and Vos, 2021, 2023; FAO, 2022; Mukherji et al. 2023).

Several of these innovations have proven potential to both raise productivity and reduce emission intensity in agri-food production. On a top ten list of new technologies and practices ranked by readiness, adoption potential, and potential impact, four relate to replacement food and feed for humans, livestock, and fish through plant-based substitutes, insects, microalgae and cyanobacteria, and seaweed (Barrett et al., 2020). Such innovations will be critical given livestock's contribution to global GHG emissions. For instance, sophisticated livestock breeding methods can help improve livestock productivity using advanced genetic and genomic selection methods to contribute to heat tolerance and to methane mitigation (Pryce and Haile-Mariam, 2020). Algal-derived feed supplements (e.g., seaweed) help reduce methanogenesis in ruminant digestive systems to enteric fermentation and methane generation, while improving productivity in the livestock sector (Mernit, 2018; McCauley et al., 2020). Another innovation is the use of insects as feed. Insects are often rich in protein and some vitamins and minerals (Henchion, 2017). Use of some insect-derived protein may reduce GHG emissions, though, to date, strong evidence on this impact is scant (Parodi et al., 2018). In addition, methane production in rice cultivation, another major source of GHG emissions from agricultural production, can be significantly reduced through alternate wetting and drying in rice cultivation (Chidthaisong, 2013). These promising new practices could reduce methane emissions from rice and cattle by up to 50 percent.

Innovation-based approaches that raise agricultural productivity for all producers are unlikely to create poverty and food insecurity problems for producers. By lowering food costs, they are likely to raise real incomes and lower poverty. The reduction in food prices could potentially lower the incomes of some farmers. Ivanic and Martin (2018, p434) examine a range of scenarios—such as individual small economies, developing countries and global productivity shocks—and find that increases in agricultural productivity reduce poverty in all these cases.

5.6 Demand-side interventions

Interventions on the demand side could also potentially influence emissions and other outcomes of concern. As discussed by the EAT-Lancet Commission (2019, p471), these might include dietary changes towards healthier diets, new product innovations and reductions in food loss and waste.

Much attention on dietary change has focussed on interventions designed to reduce consumption of foods that are both unhealthy and contribute to emissions (Springmann et al 2016). Considerable evidence suggests that switching to healthier diets with much reduced meat consumption from present levels would simultaneously improve people's and planetary health (EAT Lancet Commission, 2019; Willet et al., 2019; Loken and DeClerck, 2021). Beef and sugar consumption in high-income countries are frequently considered examples. While taxes on rice consumption might potentially reduce emissions from rice production, most consumption of rice is in poor countries where imposition of consumption taxes would likely have adverse impacts on poverty and food insecurity.

A challenge for this approach is that the elasticities of demand for foods are relatively low and systematically decline as incomes rise (Gouel and Guimbard 2018). This means that food taxes of any realistic magnitude are unlikely to have large impacts on demand in high-income countries. Given both the interest in health and environmental impacts, it seems likely that a range of approaches like the Nuffield ladder2 of policy interventions considered by the EAT-Lancet Commission (Willett et al 2019) would be needed in these countries.

Demand-side interventions clearly have potential to be complementary with measures operating on the production side. By reducing the demand for basic agricultural products, they also reduce the demand for agricultural land and hence the emissions associated with land use change. A reduction in demand for agricultural products in any sizeable group of countries reduces the incentive to produce both at home and abroad and so poses no risk of leakage, in contrast with approaches based on production taxes.

The low elasticities of demand for food are potentially an advantage when seeking to reduce global emissions but only some countries are willing to impose a tax. Given lower elasticities of demand than of supply, Martin (2023) shows that a consumption tax on only part of world consumption reduces emissions at lower cost than a production tax on the same share of world production. This is because demand is less internationally footloose than supply and the tax on demand brings about reductions in output in both the taxing region and the result of the world. If all of production or all of consumption can be taxed, it doesn't matter whether the tax is imposed on production or on consumption.

Another potentially promising approach on the demand side would be through product innovations that reduce the environmental footprint of food demand. Innovations such as plant-based milk and meat products have shown considerable potential. The staggeringly high cost of products such as beef (Fukase and Martin 2020) implies enormous increases in the economic and environmental costs of meeting food demand if developing countries are to reduce the gap between their income levels and those of today's high-income countries (Fukase and Martin 2020).

Reductions in food loss and waste reduce the demand for raw food products in the country achieving the reductions and, by lowering global food prices, reduce production in all countries. They therefore do not suffer from a leakage problem.

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[2] This approach involves a range of interventions organized from least interventionist—like providing nutritional information, persuasion, taxes, through to bans on consumption. The multi-faceted approach used in many countries to discourage tobacco smoking is perhaps an example.

6. Model-based analyses of policy effectiveness

In this section, we summarize available model-based scenario analysis assessing the effectiveness of different policy approaches towards mitigating GHG emissions from agriculture and the trade-offs such policies may generate with respect to other policy objectives, such as adequacy of food availability, poverty reduction and food security.

6.1 Carbon Taxes

Two model-based studies of carbon taxes on agriculture are particularly useful. A study by Jansson et al. (2024, p16) holds the carbon intensity of production constant and considers only the implications of changes in output mix on emissions, leaving out any possible impacts on via changes in technique. This is consistent with a situation in which emissions are unmonitorable and hence producers are not rewarded for changes in technique that reduce emissions. They consider taxes of around 150 Euro/ton of CO2 and compare the results of a unilateral carbon tax in Europe, such a carbon tax with an import-only carbon border adjustment mechanisms (CBAM), and global carbon taxes. Jansson et al. estimate that in a scenario of a unilateral EU carbon tax, emissions in the EU would fall by 20 megatons of CO2 equivalent (MT) and global emissions by around 4 MT or around 0.04 percent of likely global farmgate emissions in 2030. Their scenario with an import-only CBAM increases these emission reductions to around 10 MT or 0.1 percent of 2030 global emissions from farmgate agriculture[3]. The apparent relative efficacy of an import-only CBAM is specific to a situation like the EU where it appears that the import competing activities whose output is preserved may have lower emission intensities relative to the exportable activities whose output is likely decimated by the combination of the carbon tax and the cost-increasing burden of protection to import-competing activities. But clearly, emission reductions of the order of magnitude reported in this study are not sufficient to bring about the transformative reductions in emissions.

Henderson and Varma (2021) assume that producers have available methods for abating emission intensities as well as changing output levels. This assumes that emissions can be monitored, and carbon taxes imposed to create incentives to use these technologies. With this assumption, they concluded that a carbon tax of $100 per ton of CO2 equivalent in an OECD+ group accounting for 45 percent of global agriculture would result in a 9.6 percent fall in the non-CO2 emissions that make up three quarters of total agricultural emissions. In their analysis, allowing for change of technique dramatically increased the impact of a carbon tax, with the impact of a $100 carbon tax in the OECD increasing by a factor of more than 3 when changes in technique were allowed (Henderson and Varma 2021, Figure 1). In their analysis, the impact of a carbon tax on emissions also depends critically on the country coverage, with increases in coverage up to around 45 percent of global emissions sharply reducing leakage.

6.2 Repurposing of Agricultural Support

Substantial evidence on the impacts of several approaches to reducing emissions is available from the recent IFPRI-World Bank study of repurposing agricultural support (Gautam et al. 2022). This study uses IFPRI's MIRAGRODEP model (Bouët et al. 2022) augmented with modules to track emissions, land use change, poverty,

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[3] FAOSTAT reports farm gate emissions of 7,756 MT in 2020 and these are projected to grow by around 25 percent to 2030 to around 9,700 MT in 2030

and food security impacts. The global results from this study are usefully presented on a single chart, Figure 11, to highlight contrasts between the different approaches.

The first scenario considered is abolishing domestic support—perhaps the largest change in this form of support that might be considered. This change would reduce agricultural GHG emissions by about 103 MT of CO2eq, a small reduction relative to total emissions and to the gains achievable using other approaches. These reductions would be induced by a decline in the use of agricultural inputs and factors. The environmental gains would vary across countries, reflecting the level of support provided by individual countries—hence the reduction in GHG emissions would be larger for developed than for developing countries. The removal of support would reduce the amount of land under agriculture by a substantial 27 million hectares by 2040. This land savings would directly contribute to an increase in forest habitat, helping preserve biodiversity and reduce GHG emissions through sequestration.

On the one hand, the removal of economic distortions created by distortionary domestic support would generate efficiency gains, raising real world income in 2040 by about $74 billion per year relative to the baseline.[4] On the other hand, such reform would face a major political economy challenge because it would lead to a decrease in farm output, reinforcing some policymakers' concerns about food security. These reductions in output would drive up global prices, but despite the price increases, real farm incomes per worker would decline by about 4.5 percent globally, with larger declines in developed countries (11.4 percent) than in developing countries (2.7 percent). The decline in food output would raise the cost of healthy diets, making it more difficult for people to maintain access to healthy diets. The rise in food prices would also raise poverty slightly.

The second repurposing scenario considered is the removal of all support, including border measures. This change yields larger economic gains because it involves removal of distortions to consumption as well as production. However, its impacts on global food output are smaller because, as previously noted, this form of support raises the global cost of food. While it increases food production in protected countries, it reduces production elsewhere. Its climate impacts and impacts on agriculture's land footprint are also smaller than for removal of domestic support because of the smaller change in global output.

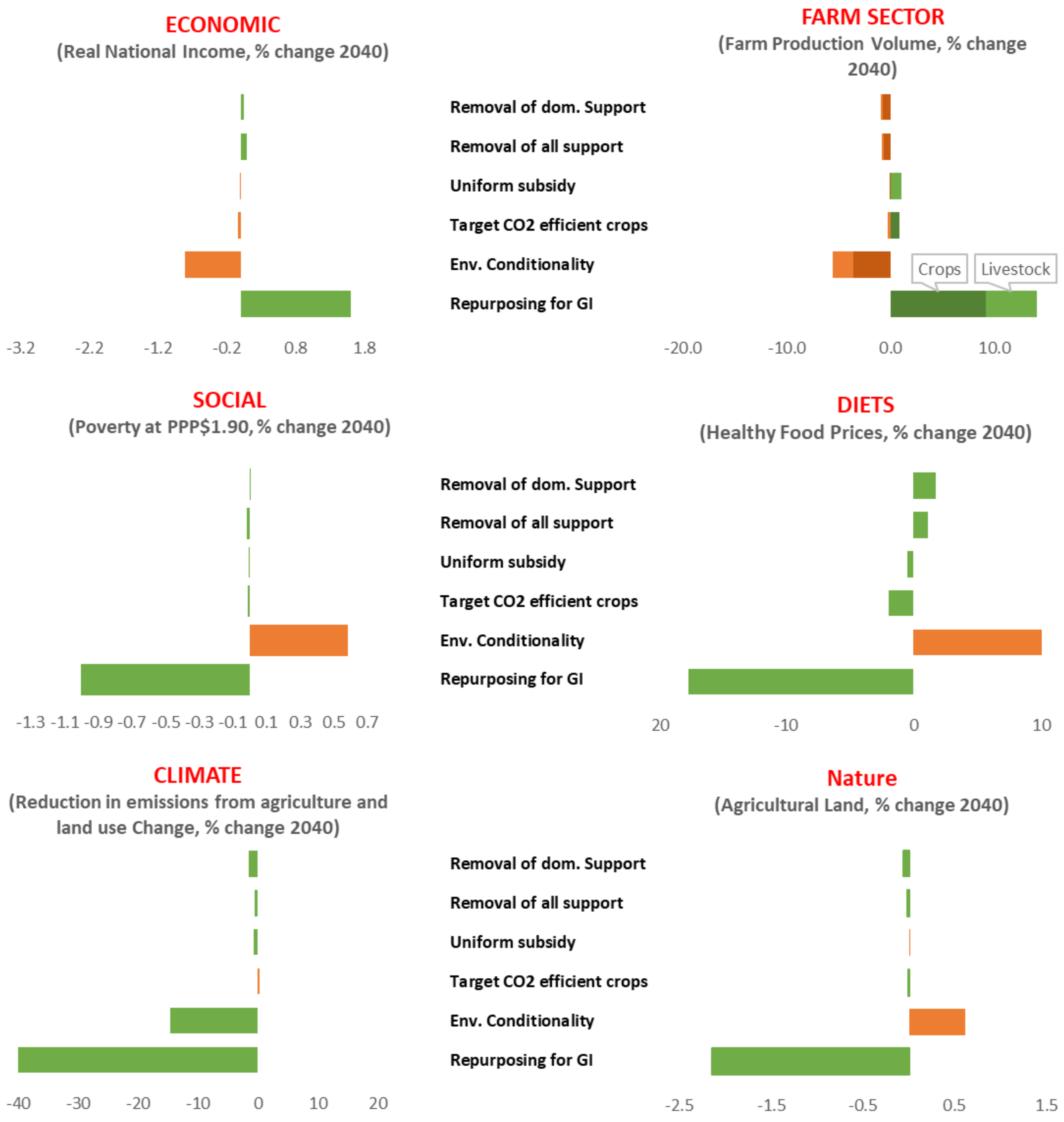
The third simple repurposing scenario involves moving domestic support to a uniform subsidy across crops in each country. Surprisingly, this generates negative economic welfare changes, presumably because this move to uniform support takes place in the context of continuing trade distortions and hence yields a negative second-best welfare impact. Farm production, however, increases slightly. This change has a negligible impact on poverty but slightly reduces the average cost of a healthy diet. The impacts on climate and nature are extremely small.

The final simple repurposing scenario considered is a move from the current allocation of subsidies across commodities to products such with relatively low emission intensities. This has small adverse impacts on economic efficiency but does increase farm output volume because of the move away from resource-intensive livestock products towards crops. It lowers the cost of healthy diets, while having almost no impact on poverty rates. Its impacts on emissions are slightly adverse—likely because it lowers the cost of livestock feeds by targeting commodities such as maize—and slightly increases demand for land.

A tentative conclusion from this analysis of rearrangement of current subsidies and overall support is that none of the changes considered appear to have much prospect for achieving the needed transformational reductions in emissions. Some, such as removal of all subsidies, have adverse global impacts on the costs of healthy diets.

[4] Economic efficiency gains were calculated using the projected estimate of global real GDP of $149.8 trillion in 2040 (an increase of 82.1 percent from the 2017 real GDP of $81.7 trillion).

Figure 11: Global Implications of Repurposing Domestic Support (% change relative to baseline projections for 2040)



Source: Gautam et al. 2022.

6.3 Regulatory approaches

A fourth scenario introducing environmental conditionality as part of repurposed support is relevant to a wider range of regulatory changes. The scenario assumes that producers are willing to undertake changes—such as moving to organic agriculture that they would prefer not to undertake—in preference to losing their current levels of support. This has essentially the same economic and welfare impacts as a simple regulatory requirement to undertake these reforms (Figure 11). These impacts are similar to those of a PES approach, except that recipients of PES funding would gain from the direct, new payments made to induce them to make the change.

Drawing on the literature on emission reductions and cost increases associated with existing policy proposals for this type of conditionality, this illustrative simulation makes farm support conditional on increased use of production techniques based on application of organic fertilizer and pesticides and with the assumption this would reduce emission intensities by 10 percent, while also raising production costs by 10 percent. Adoption of such a policy by all countries would reduce global GHG emissions from agricultural production by 19 percent owing to the reduction in emissions per unit of output and to a decline in global output caused by increased production cost and lower productivity associated with organic farming (Ponisio et al. 2014). However, this gain is expected to be offset by increases in emissions from land-use change, because lower global output would induce farmers to bring additional land under cultivation. The net reduction in emissions from agriculture and land-use change would be 15 percent. This gain would come at cost of a 0.8 percent decline in global income, and a drop of more than 5 percent in agricultural production, while poverty and the cost of a healthy diet would both increase. Decreased biodiversity would incur additional losses since an increase in the use of land for agriculture would result in the loss of forest habitat.

6.4 Credits for Emission Reductions

As noted in the earlier discussion, a key challenge for approaches that provide credits for emission reductions brought about in another country suffer from intense problems with definition of the baseline. The only available quantitative research on the global impacts of these approaches (Calel et al 2025) conclude that the problems with the definition of the baseline are extremely challenging, particularly because many of the observed reductions in emissions associated with sponsored projects are likely to be inframarginal—that is to have happened even in the absence of the intervention. On the basis of a detailed analysis of wind farm projects in India, they concluded that 52 percent of projects would have been implemented even in the absence of the credits.

When the problems associated with the inframarginal nature of many sponsored projects are weighed together with the enormous challenges associated with fraudulent projects, it seems unlikely that this approach can be relied upon to achieve the transformational reductions in emissions needed to address the challenges of global warming. Reducing the support provided to projects suspected of being economic in the absence of credits might help mitigate the problem of infra-marginality, but only by focussing credit programs on projects that are higher cost.

6.5 Green Innovations

The key point of departure in the repurposing for green innovations (GI) is a focus on green innovation; that is, technologies and practices that would reduce emissions while increasing productivity. Recognizing that achieving this is not without cost, the focus of this scenario is on redirecting some of the domestic support currently provided to agriculture toward more public spending on research and development (R&D), and incentives for the development and adoption of green innovations. Some such innovations already exist or are emerging. Based on an examination of the literature on the potential of recent innovations to raise productivity and reduce agricultural emissions, this illustrative scenario assumes a 30 percent increase in production and a 30 percent reduction in emissions per unit of output. The literature on past agricultural productivity growth suggests that the cost of raising agricultural productivity by 30 percent on a sustainable basis would be roughly equivalent to one percent of the value of farm output. This scenario considers repurposing the equivalent of one percent of the value of farm output from the current domestic support for agriculture to invest in R&D, under the assumption that with reoriented R&D priorities, this level of research intensity would also apply to the generation of green innovations.

As is evident from Figure 11, this scenario has much to commend it. Economic efficiency increases because of the fall in the cost of production and farm output rises. The resulting decline in the cost of food sharply reduces the cost of healthy diets and lowers poverty more than under any other scenario considered. Emissions fall sharply because of the reductions in emissions and the reduction in the need to convert land for use in agriculture. The decline in agricultural land use creates opportunities for increases in biodiversity.

6.6 Demand-side interventions

A comprehensive set of demand-side interventions is considered by Glauber and Laborde (2023). These are performed using the same MIRAGRODEP model as in Gautam et al (2022) and involve repurposing current domestic support measures into consumer subsidies. The first column in Table 2 refers to the case where producer subsidies are repurposed into uniform consumer subsidies across all foods. The second refers to the case where subsidies are targeted to the high-priority foods that are most under-consumed relative to dietary guidelines for that particular region. In this case, subsidies are applied to fruits and vegetables in almost all regions, while dairy and fishery products are subsidized only in relatively low-income countries.

Table 2. Repurposing of domestic support into consumption subsidies

	Prevalence of undernourishment	Affordability of a healthy diet	Extreme poverty	Farm Income	Agricultural production	Agricultural production	Land use emissions	Total emissions
Uniform subsidies	-0.10	0.38	-0.08	-4.18	-0.23	-0.59	-0.42	-0.43
Targeted consumer subsidies	-0.05	0.77	-0.06	-3.74	-0.20	-0.61	1.07	-0.18

Source: Glauber and Laborde (2023)

As can be seen in Table 2, transforming support into uniform consumption subsidies on all foods causes a small reduction in emissions from agricultural production and from land use change. It also reduces the prevalence of undernourishment but increases the affordability of a healthy diet. Because it lowers the cost to consumers of food, it reduces the share of people in poverty. Farm incomes fall because of the loss of production subsidies.

Targeted consumer subsidies favor consumption of fruits and vegetables in virtually all regions, dairy products in many regions and meats in just over half of all regions. This targeted subsidy scenario reduces emissions from agricultural production, while increasing them from land use change, for a very small overall reduction in emissions from agriculture and land use change. This scenario improves the affordability of healthy diets while lowering undernourishment and overall poverty.

Springmann et al. (2017) examine the impacts of imposing a carbon tax at a $52 per ton of CO2eq on the consumption of food, using estimates of emission intensities in production in different regions—implying that tax rates are higher in lower-income regions where emission intensities are generally higher. They conclude that a global tax of this magnitude would generate a reduction of 9.3 percent in emissions linked to agriculture. In addition, they conclude that it would greatly lower the risks of noncommunicable diseases associated with diets. This result is much larger than the results reported by Glauber and Laborde (2023) and reflects the fact that the intervention is imposed as a tax rather than a subsidy, the much higher rate of intervention and the fact that this intervention is imposed globally, rather than depending on the country's current level of budgetary support.

Their findings are relatively robust to factors such compensation for the higher costs of food and exclusion of fruit and vegetables, staples and legumes. Increasing the tax rates to $100/ton or higher would substantially reduce emissions. While even these results are not transformational, they suggest that demand interventions with compensation as needed could play a role in a package designed to reduce emissions. As noted in Section 5, a range of interventions in addition to food taxes will be needed to simultaneously improve diets and food security, while reducing emissions.

7. Summary and Conclusions

GHG emissions from the agrifood sector are far too large—at roughly a third of total net emissions—to be ignored given the need for massive and timely reductions in global GHG. These emissions are also highly decentralized by economy. Of the six economies that account for 50 percent of emissions, only two (the EU and the USA) are high income economies while the other four (China, Brazil, India and Indonesia) are developing countries. Even the top 20 countries account for only 72 percent of total emissions, suggesting that reductions in a much wider range of countries are needed if emissions are to be reduced in line with the IPCC goal of halving emissions. These emissions are also projected to grow rapidly, with farm gate emissions projected to grow by 58 percent between 2020 and 2040.

The 23 percent of emissions from farmgate agriculture and land use change present special challenges and opportunities. Unlike emissions from the rest of the economy, where emissions from fuel combustion dominate, these emissions are predominantly decentralized process emissions for which economists' preferred tool of carbon taxes are much less likely to work successfully given the challenges involved in monitoring and rewarding reductions in emission intensities. With emissions from combustion, emissions are largely in fixed proportion to fuel use, making monitoring of reductions in actual emissions unnecessary. With decentralized process emissions such as methane emissions from enteric fermentation, reductions in emissions need to be monitored and rewarded if measures such as carbon taxes are to encourage the changes in technique needed to obtain the full benefits from measures such as carbon taxes.

Farmgate emissions do, however, provide opportunities for rapid reductions in global warming contributions because 73 percent of these emissions are from methane (CH_4) and nitrous oxide (N_2O) which are super-potent greenhouse gases in the short term, although their lifespans in the atmosphere are lower than for CO_2. Prompt reductions in these emissions could sharply lower the global warming effect of total emissions, potentially providing more time for reductions in emissions of other gases.

At least five broad approaches to achieving emission reductions can be identified: (i) emission taxes, (ii) repurposing of agricultural support, (iii) regulatory approaches, (iv) innovation-based approaches, and (v) demand-based approaches. Each of these, and their interactions, need to be considered in designing packages of reforms that can achieve not just reduction in emissions but broader goals such as reducing poverty and hunger and maintaining biodiversity.

As previously noted, emission taxes that contribute both by creating incentives to use lower-emission technologies and to reduce output of emission-intensive outputs are less effective for the decentralized process emissions that dominate in agriculture. As in other applications, they also face the problem of leakage, where emission reductions in one country are offset by increases in other countries. Model-based analyses suggest that carbon taxes that merely affect output levels, without changing the techniques used, would have little impact on global output. While approaches that monitor and reward actual reductions in emissions, and so encourage changes in production technique, could yield worthwhile reductions in emissions, the challenges of doing this look very serious.

Much attention has focused on the potential repurposing of the vast sums of money—both from Treasuries and from consumers—currently transferred to agriculture. Agricultural subsidies are particularly important because they unambiguously increase global farm output and, at current technologies, increase emissions. While potentially very important for improving economic efficiency, (in-principle) simple changes such as abolishing all production subsidies or reallocating them across crops appear to have only very small impacts on global emissions.

Regulatory approaches such as mandatory changes in production techniques or conditioning payment of subsidies on specified changes in production techniques seem likely to be able to achieve sizeable reductions in farmgate emissions. One weakness is that they require the regulator, rather than market participants with better knowledge of their activities, to identify the best way to reduce emissions. Another is that they involve monitoring and compliance challenges that are likely particularly challenging in agriculture. Another problem in agriculture is that, by lowering agricultural productivity, they make it necessary to use more agricultural land, generating emissions from land conversion and reductions in future forest sequestration.

Perhaps the most promising approach to mitigating emissions from the agrifood sector involves investments in R&D designed to yield green innovations that yield both lower emission intensities and lower production costs. Such innovations are impervious to leakage since they increase the market share of the now cleaner producers. They also help achieve other goals, like raising economic efficiency, lowering poverty, reducing undernutrition and the costs of healthy diets. Because they increase yields, they reduce the need for agricultural land and hence emissions from land use conversion.

Mitigation approaches based on demand interventions may also play a role. These interventions are frequently thought of as targeting over consumption of products like red meats in rich countries. In general, these measures are unlikely to result in leakage, since they reduce production in both the countries that impose them and those that do not.

Reducing emissions from the agrifood sector while contributing to other objectives such as lowering poverty and food insecurity is likely to require a range of interventions that deal with the fact that most of these emissions are decentralized process emissions that are extremely difficult to monitor. This reduces the potential role of measures like carbon taxes and increases the need to rely on other measures such as regulatory approaches, green innovations, or demand-side interventions. Given our multiple objectives, a mix of interventions is likely to be needed with particular emphasis on funding and discovering innovations that sharply reduce emissions and increase productivity, so their adoption is attractive, and challenges of monitoring and compliance are diminished.

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