AGRICULTURE AND FOOD SERIES

OVERVIEW

RECIPE FOR A LIVABLE PLANET

Achieving Net Zero Emissions in the Agrifood System

WORLD BANK GROUP

William R. Sutton, Alexander Lotsch, and Ashesh Prasann

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FOREWORD

We are faced with a startling and largely misunderstood reality: the system that feeds us is also feeding the planet's climate crisis. The world's agrifood system emits about 16 gigatons of greenhouse gasses per year, about a third of all global emissions, and is projected to keep growing. At this rate, the Paris Agreement's goal of limiting global heating to 1.5°C by 2050 becomes impossible. The narrative is clear: to protect our planet, we need to transform the way we produce and consume food.

The good news? The ingredients that comprise the *Recipe for a Livable Planet* are already in the pantry.

This report lays out a recipe for transforming the agrifood system from an adversary to an ally in the fight against climate change. The authors show that there are affordable and practical measures currently available to get agrifood system emissions to net zero.

Every country possesses unique opportunities to reduce agrifood emissions tailored to its economy and natural environment. High-income countries can help the developing world reduce agrifood emissions through technology and climate finance and reflect environmental costs in the price of domestically produced, high-emitting foods to drive demand toward sustainable alternatives. Middle-income countries, where most of the cost-effective mitigation opportunities are to be found, can slow down the conversion of forests to pasture and take steps to cut methane in livestock and rice. Meanwhile, low-emitting developing countries have the chance to go straight to green technologies, leading the way toward a new development model and healthier planet.

Governments need to create the legal and economic conditions to facilitate this transformation. The mobilization of finance is essential, both through increased investment and the repurposing of subsidies that encourage environmentally harmful practices. This unified action must be inclusive, safeguarding the most vulnerable people on the frontlines of climate change and food insecurity.

The report underscores the necessity for innovation, bolstered by rigorous research and development, to unlock new methods of sustainable production. This comprehensive recipe is both possible and pragmatic—it promises an agrifood system that is secure and resilient to climate pressures while improving livelihoods and generating sources of employment. By uniting around this strategic and humane approach, we can cultivate an agrifood system that nourishes the planet and its people, ensuring the well-being of current and future generations.

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FoodSystems 2030

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MAIN MESSAGES

Introduction

Recipe for a Livable Planet is the first comprehensive global strategic framework for mitigating the agrifood system's contributions to climate change. It shows how the system that produces the world's food can cut greenhouse gas (GHG) emissions while continuing to feed the world. The report's main messages are

- The global agrifood system presents a huge opportunity to cut almost a one-third of the world's GHG emissions through affordable and readily available actions.
- These actions will also have three key benefits: they will make food supplies more secure, help our food system better withstand climate change, and ensure that vulnerable people are not harmed by this transition.

The Challenges

Agrifood is a bigger contributor to climate change than many think. It generates almost a third of GHG emissions, averaging around 16 gigatons annually. This is about one-sixth more than all of the world's heat and electricity emissions.

Three-quarters of agrifood emissions come from developing countries, including two-thirds from middle-income countries. Mitigation action has to happen in these countries as well as in high-income countries to make a difference. It is also necessary to take a food systems approach, including emissions from relevant value chains and land use change as well as those from the farm, because more than half of agrifood emissions come from those sources.

Emissions from agrifood must be cut to net zero by 2050. This is needed for the world to achieve its goal of keeping global average temperatures from rising above 1.5°C from pre-industrial levels. Emissions from agrifood alone are so high that they could by themselves make the world miss this target.

Too little money is invested in cutting agrifood emissions, and agrifood lags other sectors in financing for climate action. Finance for reducing or removing emissions in the agrifood system is anemic at 2.4 percent of total mitigation finance.

Agrifood emissions must be cut carefully to avoid job losses and food supply disruptions. The risks of inaction, though, are even greater. Not only would inaction bring job losses and disrupt food supplies. It would also make our planet unlivable.

The Big Opportunities

The agrifood system is a huge, untapped source of low-cost climate change action. Unlike other sectors, it can have an outsize impact on climate change by drawing carbon from the atmosphere through ecosystems and soils.

The payoffs for investing in cutting agrifood emissions are estimated to be much bigger than the costs. Annual investments will need to increase by an estimated 18 times, to $260 billion a year, to halve current agrifood emissions by 2030 and put the world on track for net zero emissions by 2050. Previous estimates show that the benefits in health, economic, and environmental terms could be as much as $4.3 trillion in 2030, a 16-to-1 return on investment costs.

Some of the cost can be paid for by shifting money away from wasteful subsidies, but substantial additional resources are needed to cover the rest. The costs are estimated at less than half the amount the world spends every year on agricultural subsidies, many of them wasteful and harmful for the environment.

Mitigation action in agrifood brings with it many other benefits for people and the planet. Among the benefits are increased food security and resilience, better nutrition for consumers, improved access to finance for farmers, and conservation of biodiversity.

Mitigation in the agrifood system can contribute in many ways to a just transition. This could secure jobs, good health, livelihoods, and food security for vulnerable groups and smallholder farmers.

The Opportunities for Action in Countries and Globally

With their access to resources and technological know-how, high-income countries can play a central role in helping the world cut emissions in agrifood.

- Energy demands by agrifood are the highest in high-income countries, so such countries should do more to promote renewable energy.

- High-income countries should give more financial and technical support to low- and middle-income countries to help them adopt low-emission agrifood practices and build their capacity to effectively use new technologies.
- High-income countries should decrease their own consumer demand for emissions-intensive, animal-source foods. They can influence consumption by ensuring that the environmental and health costs borne by society are fully included in food prices. These countries can also shift subsidies for red meat and dairy toward lower-emission foods, such as poultry, pulses, or fruits and vegetables.

Middle-income countries have great opportunities to cut their agrifood emissions. These countries are where three-quarters of the opportunities exist for emissions to be cut in a cost-effective way. Fifteen large, mostly middle-income countries account for almost two-thirds of the world's cost-effective mitigation potential.

- One-third of the world's opportunities to reduce agrifood emissions in a cost-effective way relate to land use in middle-income countries. Reducing the conversion of forests to croplands or pastures and promoting reforestation or agroforestry can bring big emissions cuts and store carbon in biomass and soils.
- Other opportunities exist in cutting methane in livestock and rice paddies, as well as using sustainable soil management to store carbon and boost agricultural yields and climate resilience.
- Middle-income countries easily emit the most pre- and post-food production emissions, particularly from fertilizer production, food loss and waste, and household food consumption. However, there are cost-effective options for emissions cuts in each of these areas.

Low-income countries should focus on green and competitive growth and avoid building the high-emissions infrastructure that high-income countries must now replace.

- More than half of the agrifood emissions in low-income countries come from converting forests to croplands or pastures; thus, preserving and restoring forests can be a cost-effective way to reduce emissions and promote sustainable economic development.
- Carbon credits and emissions trading can put a value on forests' standing that preserves them as carbon sinks, a refuge for animals and plants, and a source of sustainable jobs for Indigenous peoples and others.
- Improved agricultural practices such as agroforestry, which integrates trees in croplands, could not only store carbon but also make the land more productive, offer job opportunities, and provide more diversified diets. Likewise, climate-smart agriculture techniques could lower emissions while offering economic gains and more resilience to climate change.

Actions at the country and global levels can create more favorable conditions for reducing agrifood emissions. Governments, businesses, farmers, consumers, and international organizations must work together to:

- Make private investments in agrifood mitigation less risky and more possible, while repurposing wasteful subsidies and introducing public policies to encourage low emissions and productivity-enhancing technologies;

- Capitalize on emerging digital technologies to improve information for measurement, reporting, and verification of GHG emissions reductions, while investing in innovation to drive the agrifood system transformation into the future; and
- Leverage institutions at the international, national, and subnational levels to facilitate these opportunities while ensuring a just transition through the inclusion of stakeholders like smallholder farmers, women, and Indigenous groups, who are at the front lines of climate change.

Conclusion

The food system must be fixed because it is making the planet ill and is a big slice of the climate change pie. There is action that can be taken now to make agrifood a bigger contributor to overcoming climate change and healing the planet. These actions are readily available and affordable.

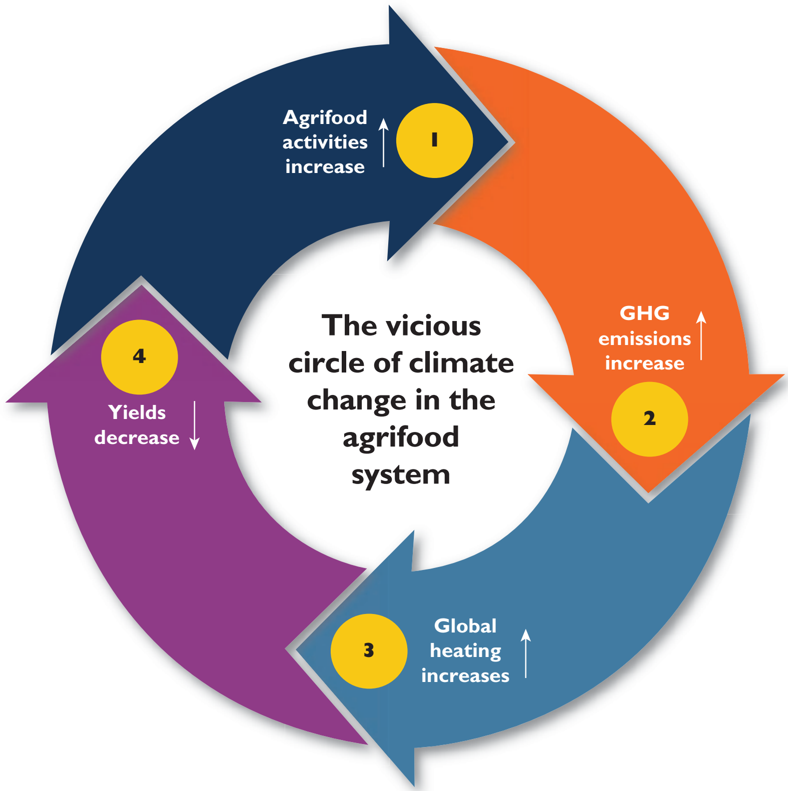
Overview

Introduction

The global agrifood system's top priority is ensuring food and nutrition security for everyone, but it also has an increasingly large role to play in protecting the planet. The Paris Agreement on climate change explicitly states that "the fundamental priority" of the agrifood system is "safeguarding food security and ending hunger" and to "foster climate resilience and low greenhouse gas emissions." Society also relies on the agrifood system to provide jobs and development while protecting the environment and promoting human health (Willett et al. 2019). However, conventional agriculture and food production often degrade soils and natural ecosystems and contribute to deforestation, biodiversity loss, ocean acidification, and air and water pollution (IPCC 2022c; UNCCD 2022). Likewise, common diets can undermine nutrition and human development. It has also become increasingly clear that the agrifood system is one of the biggest contributors to greenhouse gas (GHG) emissions and the world's worsening climate crisis. These conditions are set to deteriorate even further as the world attempts to feed a global population that will grow by 2 billion by 2050. More food means accelerating food production, land use changes, and related emissions, which exacerbate global heating. In turn, global heating will affect future agricultural yields and food security (Bajželj and Richards 2014). To compensate, food producers will intensify activities even further, causing even higher GHG emissions in a vicious circle (figure O.1).

All dollar amounts are US dollars unless otherwise indicated.

FIGURE O.1 Positive Feedback Loops between Agrifood Activities and the Climate Have Created a Vicious Circle that Precludes Adaptation Alone as a Solution to the Crisis



Source: Original figure for this publication.
Note: GHG = greenhouse gas.

Most of the world's action to limit GHG emissions has not targeted the agrifood system, but this must change to achieve net zero emissions and limit global heating. Until now, efforts to reduce GHG emissions have focused elsewhere—on sectors like energy, transport, and manufacturing, where scaling up a few key technologies has made an important difference in reducing emissions. However, these low-hanging fruits have mostly been harvested, and emissions levels are still far from where they need to be to avert climate catastrophe. The world has avoided confronting agrifood system emissions for as long as it could because of the scope and complexity of the task, instead focusing on helping people and businesses adapt to the problem. But, according to scientists, "we cannot adapt our way out of the climate crisis" (Harvey 2022), and now is the time to put agriculture and food at the top of the mitigation agenda. If not, the world will be unable to ensure a livable planet for future generations (IPCC 2023, 21–22).

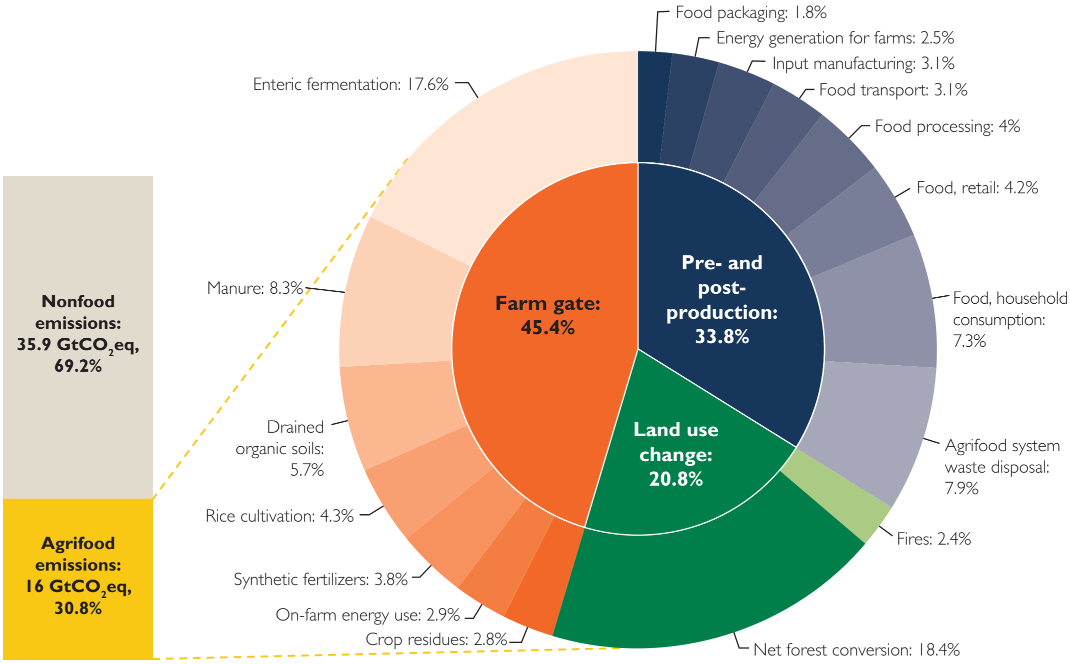
This report, *Recipe for a Livable Planet: Achieving Net Zero Emissions in the Agrifood System*, is the first comprehensive global strategic framework for mitigating the agrifood system's contributions to climate change. It identifies solutions that cost-effectively limit agrifood GHG emissions to net zero while maintaining global food security, building climate resilience, and ensuring a just transition for vulnerable groups. It identifies mitigation areas with the greatest potential for reducing agrifood system emissions for each World Bank country income category (high-, middle-, and low-income). The logic is that by focusing on the biggest emissions sources and the most cost-effective mitigation options, countries will be able to most quickly and cheaply diminish or prevent agrifood GHGs from reaching the atmosphere. This is not to say that these solutions are mutually exclusive: ideally, all countries would apply all cost-effective mitigation options immediately and concurrently. It is simply recognizing that countries have different opportunities to combat climate change through the agrifood system. The report also illuminates a path for strengthening the enabling environment for transforming the agrifood system to a net zero model through six I's: investments, incentives, information, innovation, institutions, and inclusion. Collaborative efforts among governments, businesses, citizens, and international organizations and frameworks to bolster this environment will give the world its best chance to meet the Paris Agreement's emissions targets.

This report is timely for several reasons. First, there is much more knowledge today about the global agrifood system and its growing climate footprint than there was even a few years ago. Second, it has become clear that virtually all pathways to limiting global heating to 1.5°C by 2050 will require net zero emissions from the agrifood system. Third, now is the time to drastically reorient the agrifood system, as its current form is pushing the planet beyond its operating limits. Fourth, despite the urgency, the agriculture negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) have stalled, with a particular divide between countries from the global north and south over the issue of mitigation (Puko 2023). Fifth, the World Bank, under the leadership of its new president, has announced a new vision that puts climate change mitigation and other global public goods at the center of everything it does, with a mandate to create a world free from poverty "on a livable planet" (World Bank 2023).

The Agrifood System Has a Big Climate Problem

GHG emissions from the agrifood system are significantly higher than previously thought. Previous calculations estimated that agriculture, forestry, and other land use (AFOLU) have generated about one-fifth of global GHGs (IPCC 2022b). However, more recent and holistic measurements that include pre- and post-production emissions show that the global agrifood system is responsible for significantly higher GHG emissions than previously thought: on average, 16 billion metric tons of carbon dioxide equivalent (CO_2eq) per year, or about 31 percent of the world's total GHG emissions (figure O.2) (Crippa et al. 2021; Tubiello et al. 2022). To put that into perspective, that is 2.24 billion tons, or 14 percent, more than all of the world's heat and electricity emissions.[1] However, reducing GHG emissions from the global agrifood system has received scant attention. For example, only about half of the Paris Agreement countries originally included agriculture-related GHG targets in their Nationally Determined Contributions (NDCs) (Fransen et al. 2022). The biggest contributions to agrifood system emissions come from eight key emissions sources: (1) livestock-related emissions, 25.9 percent; (2) net forest conversion, 18.4 percent; (3) food system waste, 7.9 percent; (4) household food consumption patterns, 7.3 percent; (5) fertilizer production and use, 6.9 percent; (6) soil-related emissions, 5.7 percent; (7) on-farm energy use and supply, 5.4 percent; and (8) rice production–related emissions, 4.3 percent. These categories represent the supply side of emissions, or the sources from which GHGs are emitted. It is worth noting that an examination of agrifood emissions from the demand side would paint a different picture.

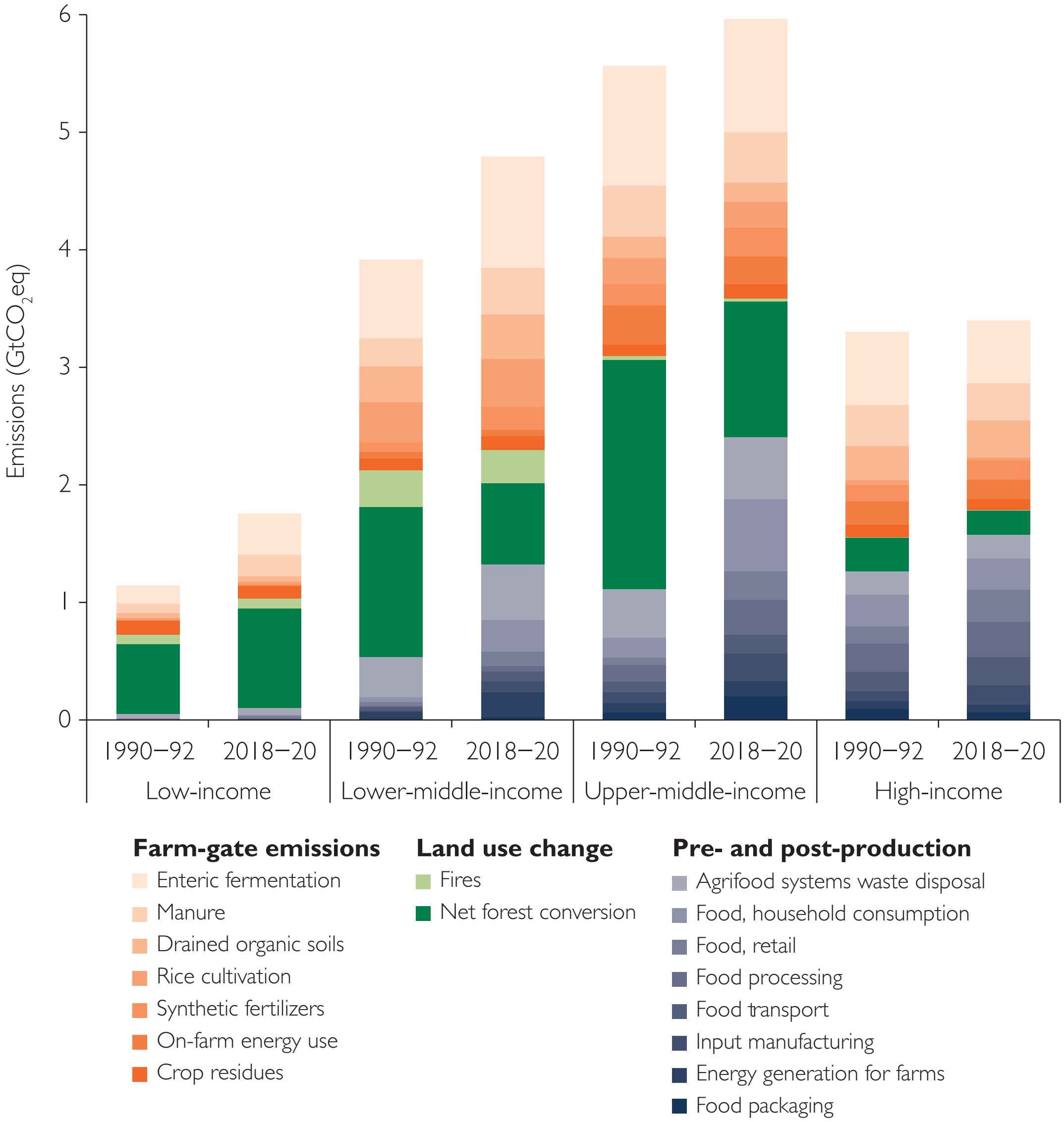
FIGURE O.2 Greenhouse Gas Emissions from the Agrifood System Are Significantly Higher Than Previously Thought



Source: World Bank analysis based on data from FAOSTAT 2023a.
Note: Left: Mean annual global greenhouse gas (GHG) emissions from the agrifood system as a share of total GHG emissions, 2018–20. Right: Emissions broken down by the three main subcategories and their individual components. $GtCO_2eq$ = gigatons of carbon dioxide equivalent.

Middle-income countries (MICs) are the biggest contributors to cumulative agrifood system emissions, while high-income countries (HICs) have the highest per capita emissions. This report analyzes agrifood system emissions by World Bank–defined country income levels—specifically, HICs, MICs, and LICs. It reveals widely diverse emissions profiles, with MICs generating most agrifood emissions both today and historically, HICs having the highest per capita emissions, and low-income countries (LICs) having the highest rates of emissions increases. Today, MICs contribute 68 percent of global agrifood emissions, compared with 21 percent from HICs and 11 percent from LICs. Note that the MIC category has the most countries, 108 worldwide, compared with 77 HICs and just 28 LICs. In that sense, it should be no surprise that MICs and their larger populations emit the most.[2] However, splitting the MIC group into lower-middle-income countries (LMICs) and upper-middle-income countries (UMICs) results in 55 LMICs and 53 UMICs but does not change the result, with agrifood emissions from each MIC sub-group far outstripping emissions from HICs and LICs (figure O.3). HICs' high per capita emissions are driven largely by the heavy consumption of meat and dairy and the increase in food transport, processing, packaging, and waste (FAO 2018). That said, HICs' share of agrifood emissions has declined as their population growth has decelerated, their economies have shifted from agriculture to manufacturing and services, they have outsourced food production to MICs and LICs, and they have invested in food sector productivity and renewable energy (Crippa et al. 2021). LICs produce the fewest overall GHG emissions from the agrifood system but have had

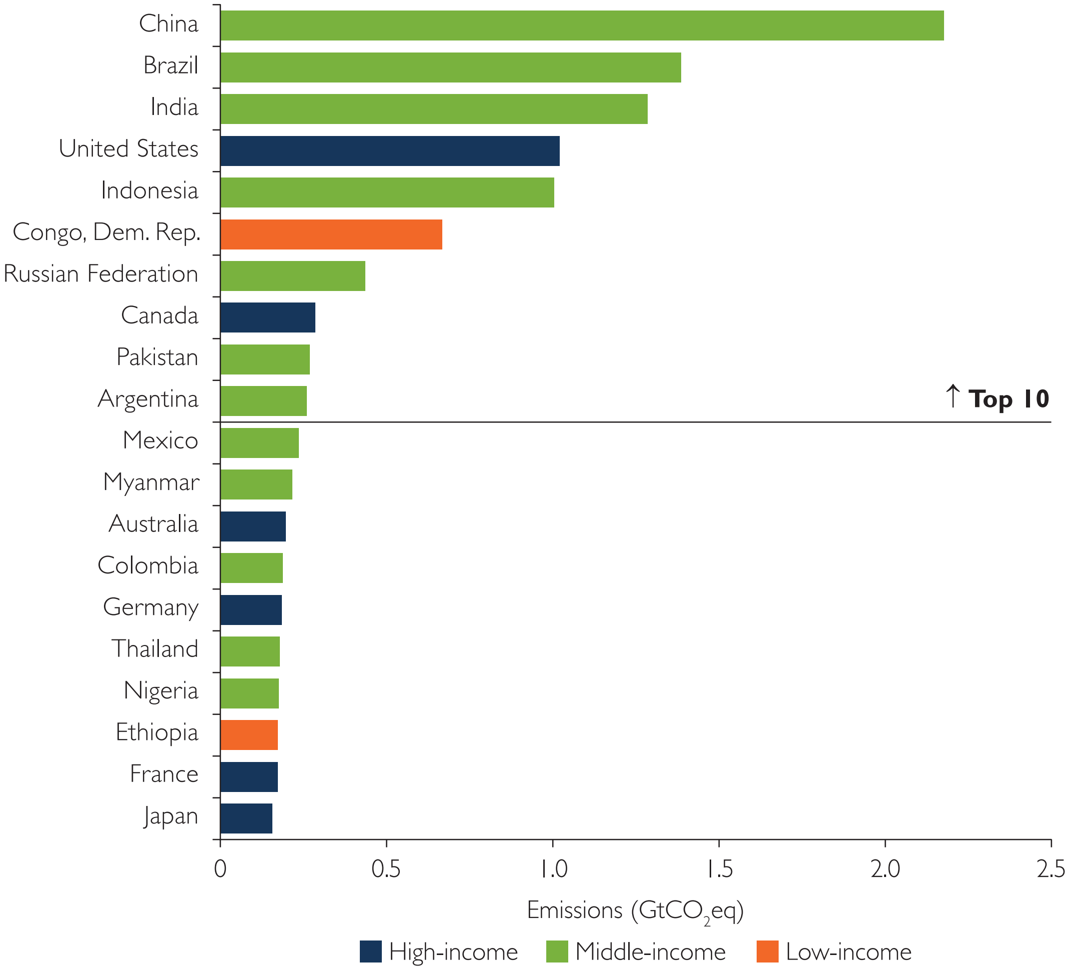
FIGURE O.3 Upper-Middle-Income Countries Generate the Highest Agrifood Emissions, Both Today and 30 Years Ago



Sources: World Bank analysis based on data from World Bank 2024 and FAOSTAT 2023a.
Note: Panel shows mean annual agrifood emissions for 1990–92 and 2018–20 by source category and country income group. Categories are grouped to reduce those with small values. "Manure" consists of manure left on pasture, manure management, and manure applied to soils. "Crop residues" consists of savanna fires, crop residues, and burning crop residues. "Fires" consists of fires in organic soils and fires in humid tropical forests. "Input manufacturing" consists of fertilizer manufacturing and pesticide manufacturing. "On-farm energy use" consists of on-farm heat use and on-farm electricity use. $GtCO_2eq$ = gigatons of carbon dioxide equivalent; HICs = high-income countries; LICs = low-income countries; LMICs = lower-middle-income countries; UMICs = upper-middle-income countries.

the highest rate of increase since the early 1990s: a 53 percent increase, compared with a 12.3 percent increase for MICs and a 3 percent increase for HICs. Digging deeper into these profiles shows that the bulk of agrifood emissions are concentrated in a handful of countries, mostly MICs (figure O.4). This trend is likely to continue because MICs are largely following the same emissions-heavy development path that HICs (Jones et al. 2023) historically followed but with much larger and growing populations.

FIGURE O.4 Seven of the Top 10 Agrifood System Emitters Are Middle-Income Countries, and One Is a Low-Income Country



Sources: World Bank analysis based on data from World Bank 2024 and FAOSTAT 2023a.
Note: Figure shows average annual agrifood system emissions for 2018–20. $GtCO_2eq$ = gigatons of carbon dioxide equivalent.

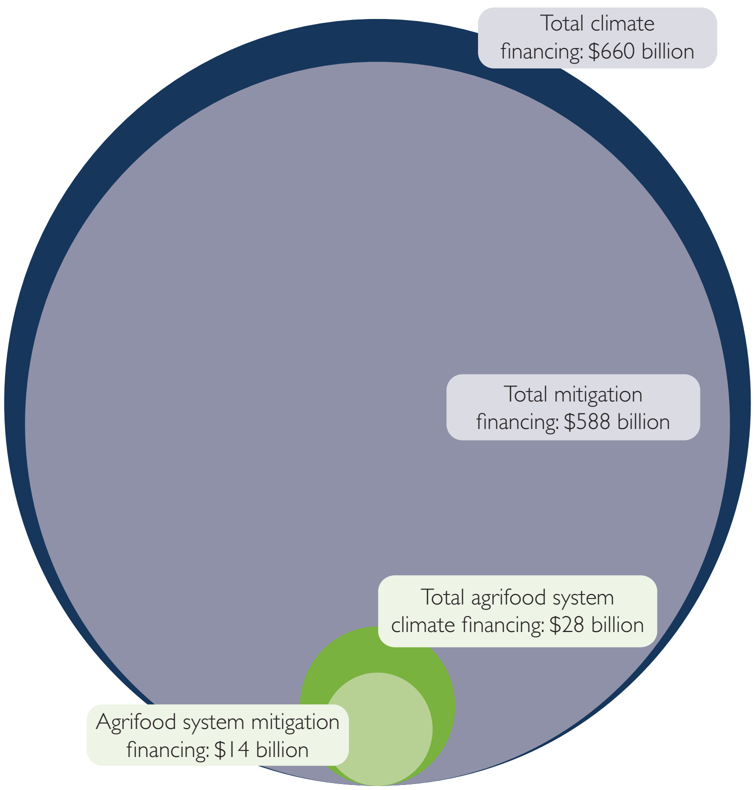
The world cannot achieve the Paris Agreement targets without achieving net zero emissions in the agrifood system. The temperature targets enshrined in the Paris Agreement reflect the scientific consensus that warming above 1.5°C from preindustrial levels threatens the most exposed countries and that warming above 2°C would lead to wide-ranging and catastrophic impacts, such as food shortages and more-destructive storms (IPCC 2018). To meet the 1.5°C target, the world would effectively need to reduce global GHG emissions from 52 gigatons per year to zero annually by 2050, with any unavoidable emissions offset by GHG-capturing activities. However, current projections, with policies in place as of 2020 and no additional action, or "business as usual," suggest that global warming would reach 3.2°C by 2100 (IPCC 2023). Moreover, recent research finds that even if all fossil fuel emissions are eliminated from every other sector, the emissions from the agrifood system alone would be enough to drive the planet past the 1.5°C threshold and even put the 2.0°C goal at serious risk (Clark et al. 2020). Therefore, the world would need to reduce net agrifood

GHG emissions from 16 gigatons annually to zero by 2050 to have any hope of meeting the 1.5°C Paris Agreement target.

There is a major financing shortfall for agrifood system mitigation. Overall, climate finance has almost doubled over the past decade (Naran et al. 2022), but project-level climate financing for the agrifood system stands at only 4.3 percent, or $28 billion, of global climate finance for mitigation and adaptation in all sectors (figure O.5). Mitigation finance for the agrifood sector was even more anemic, reaching only $14.4 billion in 2019–20, or 2.2 percent of total climate finance and 2.4 percent of total mitigation finance (CPI 2023; Naran et al. 2022). Instead, most climate finance is dedicated to other sectors, such as renewable energy, which receives 51 percent of financing, or low-carbon transportation, which receives 26 percent of financing (Naran et al. 2022). This report estimates that annual investments in reducing agrifood emissions will need to increase by 18 times, to $260 billion, to reduce current food system emissions by half by 2030.

If not done carefully, there could be short-term social and economic trade-offs in converting to a low-emission agrifood system. Some studies predict that agrifood system reforms, if not designed carefully, could lead to less agricultural production and higher food prices (Hasegawa et al. 2021). For example, reducing fertilizer or adopting organic farming would reduce emissions by 15 percent but could also reduce agricultural production by

FIGURE O.5 **Finance for Mitigation in the Agrifood System Is Strikingly Low Relative to Its Importance**



Sources: World Bank analysis based on data from CPI 2023 and Naran et al. 2022.
Note: Figure shows for 2019/20 global tracked project-level climate finance ($, billions) for adaptation, mitigation, and dual-purpose action economywide and for the agrifood system.

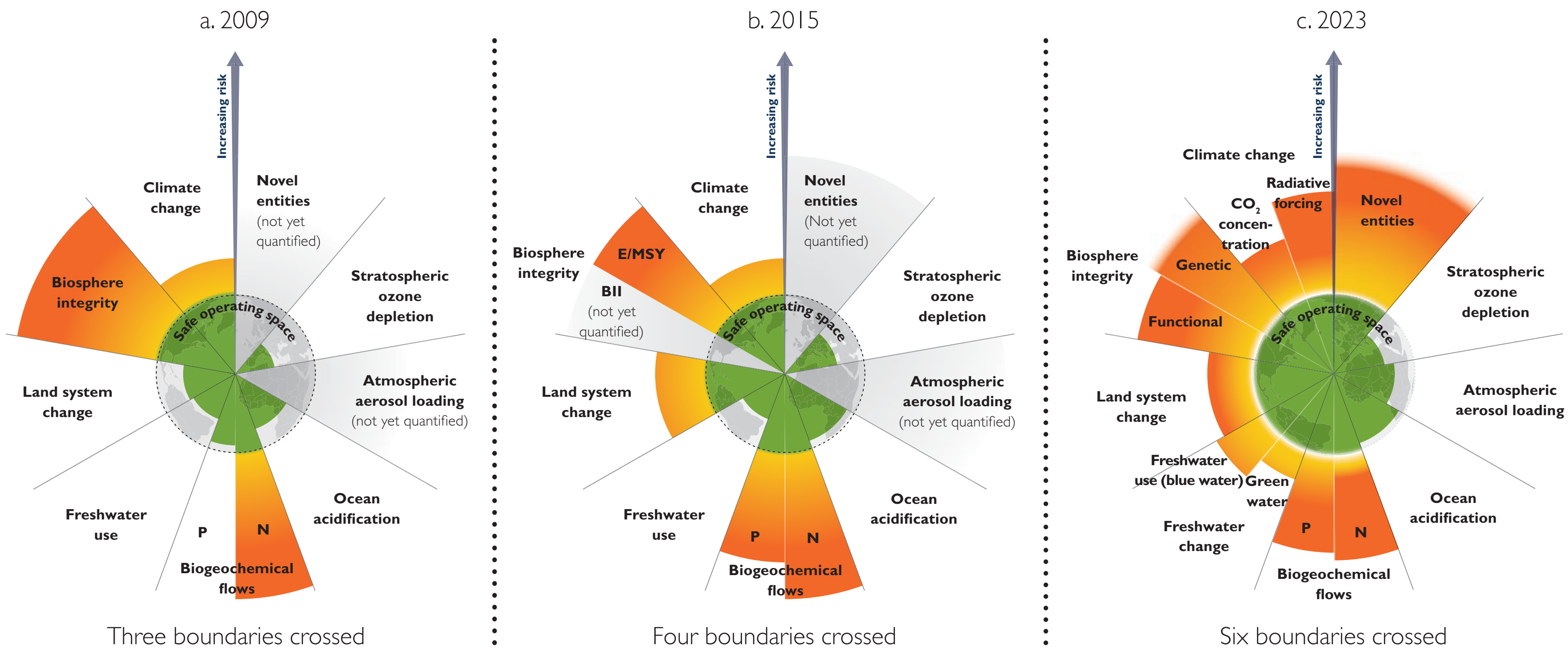
5 percent, increase world food prices by 13 percent, and raise the cost of healthy diets by 10 percent (European Commission 2020). Other studies have been even gloomier, projecting that afforestation measures could put 40 million people at risk of food insecurity by 2050 (Fujimori et al. 2022). Likewise, emissions pricing schemes would inherently increase prices for high-emitting foods, disproportionately affecting low-income families. Other studies predict that lowering agrifood emissions could lead to competition over land, water, and energy resources and affect jobs in LICs, where the agrifood sector accounts for 64 percent of total employment, compared with 39 percent in MICs and 11 percent in HICs. Because of these potential trade-offs, the transition to a net zero agrifood system is likely to encounter political and cultural obstacles.

The costs of inaction are even higher than the potential trade-offs. The world's food system has successfully fed a growing population but has fallen short of promoting optimal health and nutrition goals. Starting in 2014, human health outcomes began to decline because the agrifood system's simple focus on increasing calorie availability meant that there was less attention to producing healthier foods (Ambikapathi et al. 2022). Partly as a result, adult and child obesity keeps rising (FAO et al. 2021), and 6 of the top 10 risk factors for death and disease in both men and women are diet related (Abbafati et al. 2020). However, by 2020, healthy diets were unaffordable for 3 billion people, an increase of 119 million from 2019. Likewise, the global agrifood system disproportionately and detrimentally affects poor communities and smallholder farmers who cannot compete with industrial agriculture, thereby exacerbating rural poverty and increasing landlessness (Clapp, Newell, and Brent 2017).

In addition, the globalized nature of the agrifood system entails food price volatility. For example, over 122 million more people faced hunger since 2019 because of supply chain disruptions caused by COVID-19 (coronavirus) and repeated weather shocks and conflicts, including the Russian Federation's invasion of Ukraine (FAO et al. 2023). Besides these human costs, today's food system also causes trillions of dollars' worth of negative externalities every year. *Externalities*, in this case, refers to indirect costs that arise from the agrifood system that are felt not by the actor that creates the cost but by society. These global food system externalities are estimated to cause around $20 trillion in costs per year, or nearly 20 percent of gross world product (Hendriks et al. 2021). These externalities are already pushing the planet beyond its operational boundaries (figure O.6) (Roson 2017).

Transformation of the agrifood system can deliver multiple benefits without any of these trade-offs if coupled with resilience building. Investing in low-emission agriculture and transforming food and land use could generate health, economic, and environmental benefits totaling $4.3 trillion in 2030,[3] a 16-to-1 return on investment costs. Likewise, new research (Damania, Polasky, et al. 2023) shows that climate-smart practices that combine adaptation and mitigation measures could increase cropland, livestock, and forestry incomes by approximately $329 billion annually while at the same time increasing global food production by enough to feed the world until 2050, without losses in biodiversity or carbon storage levels. According to one study, more-efficient land use could sequester an additional 85 gigatons of carbon dioxide—equivalent to over a year and a half of total global GHG emissions—with no adverse economic impacts (Damania, Polasky, et al. 2023). In addition, better production strategies and smarter spatial planning can improve crop yields and reduce agriculture's land footprint while limiting its GHG footprint and increasing global calorie production by more than 150 percent. This translates to an 82 percent increase in net value from the world's current crop, livestock, and timber production. Over the long term (2080–2100), the benefits are much clearer. Early mitigation action is projected to lower

FIGURE O.6 **Environmental Pressures Are Surpassing Many Planetary Boundaries**



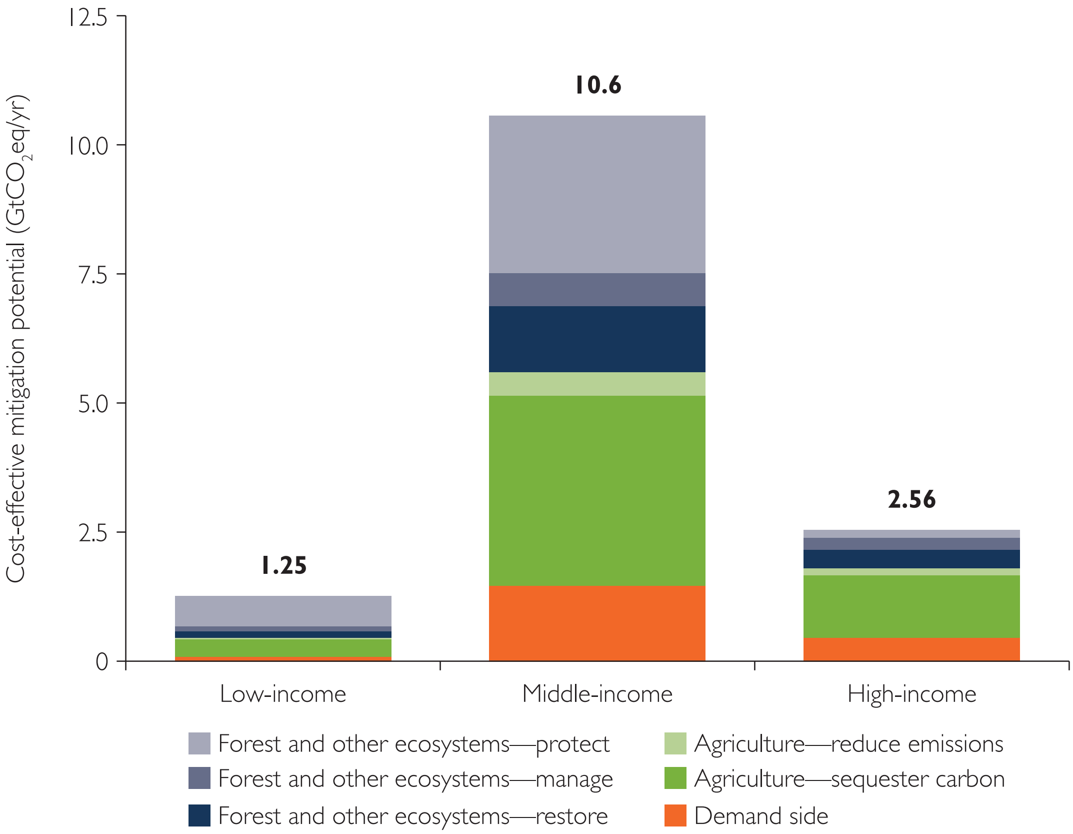
Source: Azote for Stockholm Resilience Centre, Stockholm University. Based on Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009.
Note: BII = Biodiversity Intactness Index; CO_2 = carbon dioxide; E/MSY = extinctions per million species-years; N = nitrogen; P = phosphorus.

long-term food prices by 4.2 percent, hunger risk for 4.8 million people, and water demand for irrigation by 7.2 cubic kilometers (km^3) per year (Hasegawa et al. 2021).

Country Mitigation Potential: Every Country Can Harness Priority Opportunities to Achieve Net Zero Agrifood Emissions While Advancing Development

There are cost-effective mitigation opportunities for all countries, but they depend on each country's relative circumstances. Fifteen large countries account for 62 percent of the world's cost-effective mitigation potential (figure O.7). Eleven of these countries are MICs. Cost-effective mitigation potential is the technical mitigation potential that is available and costs less than \$100 per ton of CO_2eq reductions.[4] Among country categories, 73 percent of cost-effective AFOLU mitigation opportunities are in MICs, 18 percent are in HICs, and 9 percent are in LICs. The Intergovernmental Panel on Climate Control (IPCC) estimates that 39 percent (5.3 gigatons of CO_2eq [$GtCO_2$eq]) of the cost-effective mitigation potential is achievable at costs below \$50 per ton of CO_2eq, including 28 percent (3.8 $GtCO_2$eq)

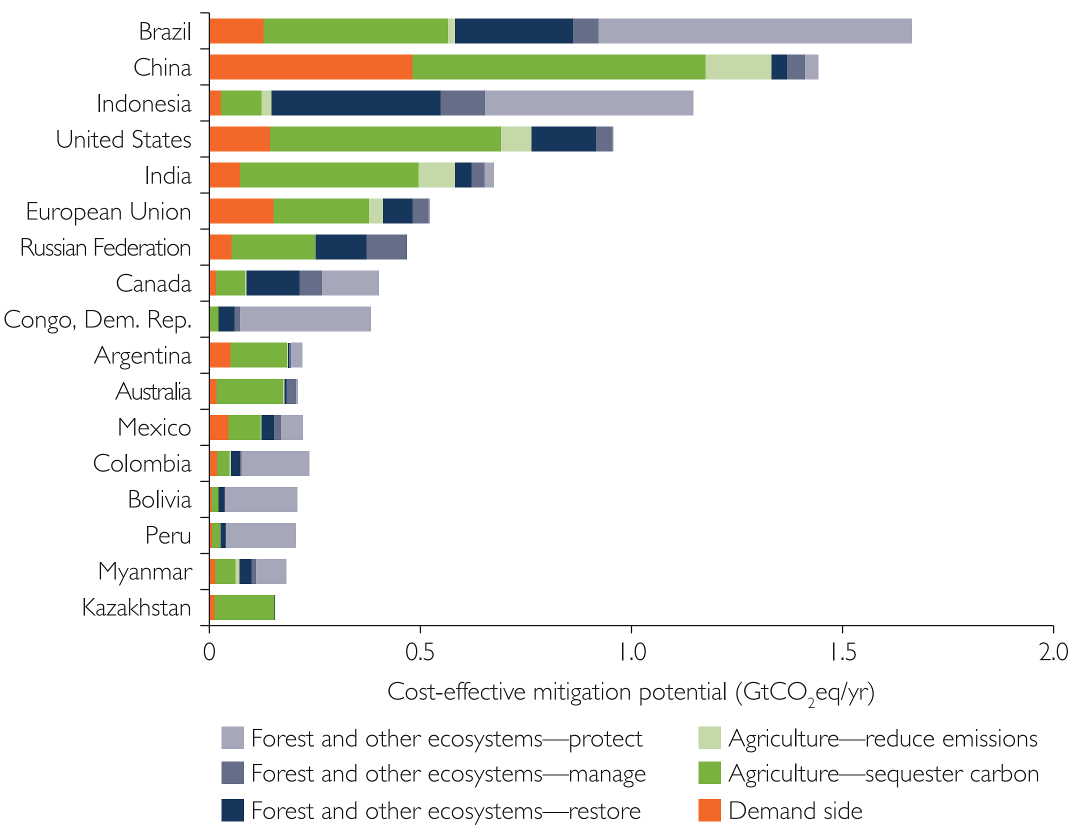
FIGURE O.7 **The Most Cost-Effective Mitigation Potential Is in Middle-Income Countries**



Sources: World Bank analysis based on data from Roe et al. 2021 and World Bank 2024.
Note: Figure shows for 2020–50 the average annual cost-effective mitigation potential by country income group and measure. $GtCO_2$eq/yr = gigatons of carbon dioxide equivalent per year.

at less than \$20 per ton of CO_2eq (Nabuurs et al. 2022). Moreover, some countries have mitigation options with negative costs (less than \$0 per ton of CO_2eq), suggesting that these options can both reduce emissions and increase farm profitability. For example, 40 percent of current methane emissions could be avoided at no net cost when co-benefits are accounted for (IEA 2023b). Such cost-saving mitigation options account for more than a third of technical mitigation potential in China's agriculture sector, half in India's, and three-quarters in Bangladesh's. A country's pathway to cost-effective emissions reductions is shaped by its natural endowments and other factors. For example, Brazil is a large, heavily forested, meat-producing and -consuming MIC that has the highest cost-effective mitigation potential in Latin America and the Caribbean. This is because many cost-effective measures are available for the country to take to reduce food system emissions, from protecting and restoring forests to shifting to healthy and sustainable diets and sequestering carbon in agriculture (figure O.8) (Roe et al. 2021).[5] In contrast, the pathway to cost-effective decarbonization is much narrower for the Democratic Republic of Congo, which is also heavily forested but has significantly less income per capita and less meat production and consumption.

FIGURE O.8 Countries Have Specific Pathways to Reducing Their Agrifood System Emissions



Source: World Bank analysis based on data from Roe et al. 2021.
Note: Figure shows for top 16 countries and the European Union the total cost-effective mitigation potential by mitigation category and measure. $GtCO_2eq/yr$ = gigatons of carbon dioxide equivalent per year.

HICs' Greatest Opportunities for Reducing Agrifood System Emissions Are From Curbing Energy Emissions, Aiding Developing Nations in Their Shift to Low-Emissions Pathways, and Fully Pricing High-Emissions Foods

The global agrifood system's energy demands are highest in HICs and are on the rise globally, but alternative low-emission energy sources provide a counterbalance. Today, energy use accounts for a third of all agrifood system emissions (Crippa et al. 2021), with most of these energy needs being met by fossil fuel–based energy. The doubling of energy-intensive pre- and post-production emissions, especially in HICs (Tubiello et al. 2022), led to a 17 percent increase of agrifood systems emissions between 1990 and 2015 (Crippa et al. 2021). Indeed, 46 percent of agrifood system emissions in HICs come from pre- and post-production processes. For comparison, 35 percent of agrifood system emissions in MICs and only 6 percent in LICs come from these processes. In fact, the food industry has the slowest progress in energy efficiency among economic sectors (IEA 2022). Partly as a result, the world is off track to meet the sustainable development goal of doubling the global energy efficiency rate by 2030.[6] Renewable energy production is helping to change this situation. In 2022 alone, renewable energy–generated electricity avoided 600 million tons of CO_2 emissions (IEA 2022) compared to if that electricity had come from fossil fuels (Wiatros-Motyka 2023). This has impacts on the agrifood system as well. For instance, replacing one-quarter of India's 8.8 million diesel irrigation pumps with solar ones would reduce emissions by 11.5 million tons per year. This amount is more than twice as much as the 5 million tons in global emissions that electric vehicles and solar panels prevented in 2020.[7] Deploying renewables leads to other positive outcomes, such as increased employment and reduced pollution (IRENA and ILO 2022). Fortunately, the adoption of renewable energy sources is growing, with renewables accounting for 83 percent of all new electricity capacity (IRENA 2023). Most importantly, renewable energy is a cost-effective mitigation strategy, with abatement costs of only $20 to $50 per ton of carbon dioxide (Elshurafa et al. 2021).

HICs are positioned to transfer financial and technical support to LICs and MICs for agrifood system mitigation. This financial support could be in the form of grants, concessional loans, or climate finance. Such financial support is in everyone's interest, because climate change mitigation is the ultimate global public good. Moreover, many HICs are at the forefront of technological advancements. As such, they can leverage their expertise to transfer advanced technologies to LICs and MICs, empowering them to adopt low-emission agrifood system practices. However, merely transferring technology is not enough. HICs and their international partners could also lead comprehensive capacity-building initiatives to ensure that LICs and MICs can effectively utilize these technologies. That said, MICs must continue to recognize their own agrifood system contributions to GHG emissions by continuing to invest in and implement policies for climate action.

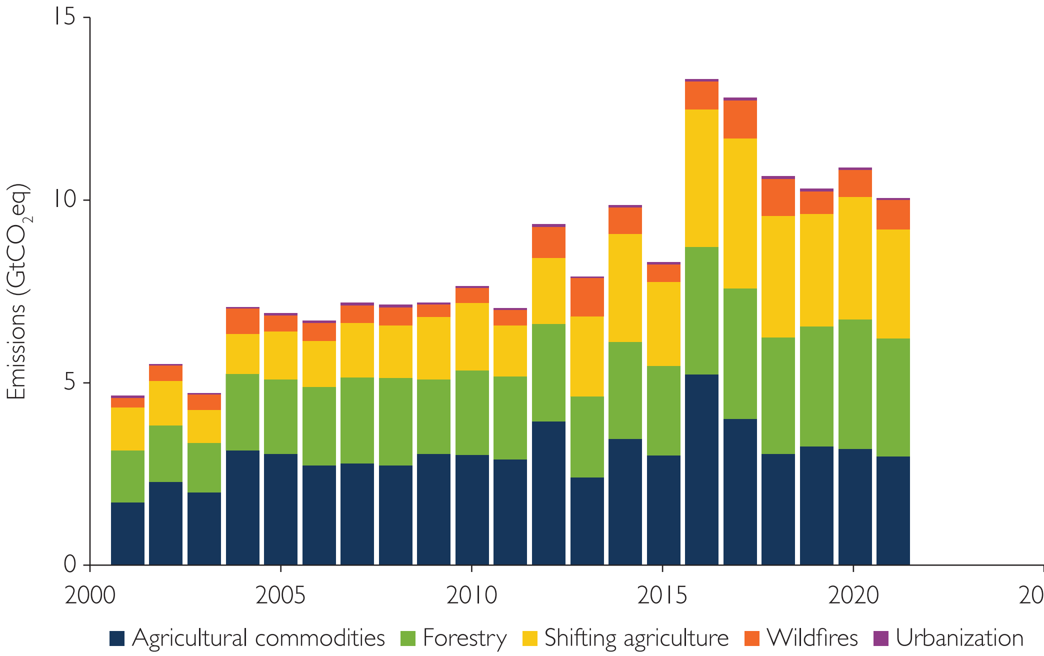
HICs can decrease consumer demand for emissions-intensive, animal-source foods by fully pricing environmental and health externalities, repurposing subsidies, and promoting sustainable food options. As global populations become wealthier, they consume more emissions-intensive foods, like meat and dairy (Ranganathan et al. 2016). HICs have the highest per capita incomes, so demand for and consumption of high-emitting, animal-source foods are greatest in those countries (Vranken et al. 2014). For example, in North America, the average citizen consumes 36 kilograms (kg) of bovine meat per year, whereas the global average is 9 kg per person per year (FAO 2023a; FAOSTAT 2023b). This trend of increased meat consumption is also occurring in MICs and LICs as their populations graduate out of poverty (Clark and Tilman 2017; Clark et al. 2020). For example, as poverty declined from 1990 to 2020, cattle meat production grew from 53 to 68 million tons, a 30 percent increase, and added close to 0.25 $GtCO_2eq$ to the atmosphere.

Currently, the demand for animal-source diets accounts for almost 60 percent of total agrifood emissions across all emissions categories (Xu et al. 2021). Thus, the cost-effective mitigation potential from shifting diets away from meat is about twice as high as that from reducing enteric fermentation and other livestock production mitigation methods. Full-cost pricing of animal-source food to reflect its true planetary costs would make low-emission food options more competitive. Globally, one-third of agricultural subsidies were directed toward meat and milk products in 2016 (Springmann and Freund 2022). Indeed, studies have shown that if prices were to reflect the true health, climate, and environmental costs of meat, meat prices would be 20–60 percent higher, depending on the type of meat (Funke et al. 2022). As a result, repurposing red meat and dairy subsidies toward low-emission foods, like poultry, pulses, or fruits and vegetables, could lead to significant changes in consumption patterns and large emissions reductions. Likewise, governments, businesses, and citizens can expand low-emission food options through (1) financial measures, (2) choice architecture strategies, (3) food labeling, and (4) education and communication campaigns. Consumer changes to healthy, low-emission diets would reduce diet-related emissions by up to 80 percent and reduce land and water use by 50 percent (Aleksandrowicz et al. 2016).

MICs Have the Opportunity to Curb Up to Two-Thirds of Global Agrifood Emissions through Sustainable Land Use, Low-Emission Farming Practices, and Cleaner Pre- and Post-production Processes

A shift to more sustainable land use in MICs could reduce a third of global agrifood emissions cost-effectively. Cropland expansion and deforestation leave a massive carbon footprint in MIC economies. Globally, deforestation contributes 11 percent of total CO_2eq emissions (IPCC 2022c), with 90 percent of that caused by expanding croplands and livestock pastures (FAO 2020). Since 2001, a few MICs with extensive forests have caused over 80 percent of commodity-driven deforestation emissions (WRI 2023). A quarter to a third of permanent forest loss is linked to the production of seven agricultural commodities: cattle, palm oil, soy, cocoa, rubber, coffee, and plantation wood fiber. A similar amount of forest loss is driven by shifting agriculture (figure O.9) (Goldman et al. 2020). The largest share of global cost-effective agrifood mitigation options comes from the conservation, improved management, and restoration of forests and other ecosystems, with reduced deforestation in tropical regions being particularly effective (IPCC 2022b). Cost-effective land use mitigation measures could avoid 5 $GtCO_2eq$ emissions per year in MICs alone (6.5 $GtCO_2eq$ globally). By some estimates, the cost of protecting 30 percent of the world's forests and mangroves would require an annual investment of just $140 billion (Waldron et al. 2020), which is equal to only about one-quarter of global annual government support for agriculture. In response, a growing number of commodity producers in these countries have introduced programs to reduce their deforestation footprint, but results are limited. There is still a lack of transparency about where many commodities come from and whether they contribute to deforestation (zu Ermgassen et al. 2022).

FIGURE O.9 **Emissions from Converting Forests to Agriculture Have Increased Since 2001**



Source: World Bank analysis based on data from Harris et al. 2021.

Note: Figure shows for 2001–21 the annual global greenhouse gas emissions by driver. Emissions—carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4)—from the gross forest loss globally are disaggregated by drivers. Forest clearing for agricultural commodities such as oil palm or cattle and shifting cultivation make up more than half of deforestation emissions. $GtCO_2eq$ = gigatons of carbon dioxide equivalent.

More than a quarter of MICs' agrifood system emissions are in the livestock sector. As of 2019, MICs caused 67 percent of GHG direct emissions from livestock, including 34 percent for LMICs and 33 percent for UMICs (FAOSTAT 2023a). By comparison, LICs contributed only 11 percent of livestock emissions in 2019. Moreover, MIC livestock emissions are on the rise. Between 2010 and 2019, MIC livestock emissions grew by 6 percent, compared with a decrease of 2 percent for HICs and an astounding 64 percent increase for LICs, although from a much lower level of initial emissions (Delgado et al. 1999). MICs also have high emissions intensity in livestock production. For example, producing 1 kg of livestock protein in MICs generated 121 kg of CO_2eq, compared with only 79 kg of CO_2eq per kg of proteins in HICs (FAO 2023d). That said, this high-emission intensity also means that livestock mitigation potential is greatest in MICs. Therefore, supply-side solutions such as reducing animal-source food loss and waste, increasing livestock productivity, limiting pasture expansion, and adopting innovative technical solutions could go a long way toward reducing agrifood system emissions to zero. However, as previously stated, demand-side measures to curb meat demand are much more cost-effective than these supply-side measures.

There are multiple avenues for mitigating emissions, particularly methane, in rice production in Asian MICs. Rice supplies around 20 percent of the world's calories (Fukagawa and Ziska 2019), but the warm, waterlogged soil of flooded rice paddies provides ideal conditions for bacterial processes that produce methane—most of which is released into the atmosphere (Schimel 2000). As a result, paddy rice production is responsible, on average, for 16 percent of agricultural methane emissions, or 1.5 percent of total anthropogenic GHG emissions (Searchinger et al. 2021). The high methane content of rice emissions means that rice's yield-scaled global warming potential is about four times higher than that of wheat or maize (Linquist et al. 2012). Notably, virtually all rice-related GHG emissions, which also include carbon dioxide and nitrous oxide, originate in MICs, and the vast majority originate in Asian countries. That said, intermittent water application and aerobic rice production methods have great potential for reducing rice-related GHG emissions while saving water. Indeed, 70 percent of the technical mitigation potential of improved rice cultivation can be achieved cost-effectively. Therefore, governments must apply policy and financing incentives and share technical knowledge with rice farmers to accelerate their adoption of these low-emission practices.

Soils could sequester about 1 billion tons of solid carbon, or 3.8 billion tons of CO_2eq, per year cost-effectively. Terrestrial ecosystems (such as forests, grasslands, deserts, and others) absorb around 30 percent of total anthropogenic CO_2 emissions (Terrer, Phillips, and Hungate 2021). The top meter of soil stores approximately 2,500 billion tons of carbon, which is almost three times the amount of carbon found in the atmosphere (Lal et al. 2021) and 80 percent of all terrestrial carbon (Ontl and Schulte 2012). This easily makes soils the biggest terrestrial carbon sink. Moreover, 12 of the 15 countries with the greatest organic carbon sequestration potential in the top 30 centimeters of soils are MICs. However, unsustainable land management practices associated with conventional agriculture have released large amounts of soil carbon into the atmosphere (Lal 2011). For example, soil organic carbon stocks in croplands and grazed grasslands are 25–75 percent lower than they are in undisturbed soil ecosystems (Lal 1999). Today, 52 percent of the world's agricultural soils are considered carbon depleted (UNCCD 2022). This issue provides an opportunity to reduce GHG emissions by restoring and sustainably managing soils. According to the IPCC, around half of the soil organic carbon sequestration potential would cost less than \$100 per ton of CO_2eq (IPCC 2022b), and about a quarter would cost less than \$10 per ton of CO_2eq (Bossio et al. 2020). Our estimates show that soil sequestration can store 3.8 $GtCO_2$eq annually for less than \$100 per ton of CO_2eq, equal to just over 1 gigaton of solid carbon.

Pre- and post-production processes are a significant and growing source of agrifood system emissions in MICs. Globally, pre- and post-production emissions account for a third of all agrifood system–related emissions and increase as countries become wealthier. In HICs, pre- and post-production emissions make up 46 percent of agrifood system emissions; in MICs, they make up 35 percent; and in LICs, they make up only 6 percent (FAOSTAT 2023a). That said, when excluding emissions from the processing-to-consumption stages of the agrifood system, which are mostly HIC energy emissions, MICs easily generate the most pre- and post-production emissions, particularly from fertilizer production and use, food loss and waste, and household food consumption. Overall, 80 percent of the world's fertilizer is consumed in MICs (International Fertilizer Association 2022). Moreover, fertilizer application in these countries is often wasteful: on average, MICs apply 168 kg of fertilizer per hectare, compared to 141 kg for HICs and 12 kg for LICs (FAOSTAT 2023c). Overall, fertilizer production and use cause 6.4 percent of total agrifood emissions. Fortunately, research shows that a combination of interventions could reduce emissions from nitrogen fertilizer production and use by up to 84 percent (Gao and Cabrera Serrenho 2023).

Another major emissions source of pre- and post-production stages is food loss and waste, which equals 30 percent of the world's food supply (World Bank 2020). In fact, 28 percent of the world's agricultural area is used to produce food that is wasted (FAO 2013; World Bank 2020). Waste reduction, especially of rice and meats, is highly cost-effective and can reduce methane at a negative cost (UNEP and Climate and Clean Air Coalition 2021). Estimates indicate that cost-effective measures to reduce food waste could reduce emissions by about nearly a half a gigaton of CO_2eq per year by 2030 (Thornton et al. 2023). Household food consumption, for its part, is the largest emissions category within pre- and post-production processes. It makes up 7.3 percent of all agrifood emissions, including 8.2 percent of MIC emissions and 7.8 percent of HIC emissions but only a fraction of a percent of LIC emissions. Most of the emissions in this category come from running household kitchen appliances. Renewable energy and clean cooking are two cost-effective measures for limiting this growing emissions category.

LICs Can Bypass a High-Emission Development Path, Seizing Climate-Smart Opportunities for Greener, More Competitive Economies

LICs contribute the least to climate change but suffer the most. Historically, LICs bear a negligible responsibility for GHG emissions and global warming, accounting for just 3.65 percent of cumulative historical emissions since 1850 (Evans 2021; Jones et al. 2023). Today, LICs contribute 4.2 percent to global GHG emissions (Climate Watch 2023) and 11 percent to global agrifood system emissions (World Bank 2024, FAOSTAT 2023a). This suggests that LICs are not yet locked into a high-emission trajectory. Currently, 53 percent of agrifood system emissions in HICs comes from the energy-intensive postharvest stages, whereas the emissions from these stages are negligible in LICs. However, this is starting to change. As countries industrialize and move up the income ladder, energy-consuming technology, such as refrigeration or food-processing machinery, tends to enter the food value chain and increase energy demand. Also, 82 percent of LIC emissions come from the agrifood system, well above the global average of 31 percent (Crippa et al. 2021), and half of LICs' agrifood emissions comes from land use, land use change, and forestry (Climate Watch 2022; Crippa et al. 2021). That said, climate change disproportionately affects agrifood systems in LICs, which are highly dependent on agriculture and have low adaptive capacity (IPCC 2022a). Moreover, the human toll in developing countries from extreme weather events is much costlier than that in developed countries, with a staggering 91 percent of disaster-related deaths occurring in poorer countries (United Nations 2021).

Preserving and restoring forests is a cost-effective way to promote development and limit the growth of LICs' emissions. Forest conversion contributes over half of LICs' agrifood system emissions, compared with 17 percent in MICs and 6 percent in HICs. Apart from Brazil, Sub-Saharan Africa has the largest block of primary forest in the world. However, the demand for agricultural commodities has been increasing the pressure on forests in LICs, and in response the forest area is shrinking—from 31.3 percent in 1990 to 26.3 percent in 2020.[8] For instance, in Congo Basin countries, there has been a 40 percent increase in land allocated for oil palm from 1990 to 2017 (Ordway et al. 2019).

In addition to conservation, forest restoration can achieve climate objectives and drive development. By one estimate, forest restoration could deliver a net benefit of $7 to $30 for every dollar invested through ecosystem services (Verdone and Seidl 2017). Agroforestry—the practice of integrating trees in croplands—produces benefits in LICs (FAO 2023b) beyond carbon storage, such as greater land productivity, livelihood opportunities, diversified diets, and greater ecosystem resilience and services (FAO 2023b). Emerging economies are beginning to monetize their forest cover and agrifood emission reductions through carbon credits and emissions trading. A global study of all country types shows that LICs can earn the highest potential income from carbon sequestration.

LICs can avoid GHG lock-in by improving agrifood system efficiency and marketing sustainable products. This GHG lock-in occurs when a country's investments or policies hinder the transition to lower-emission practices even when they are technically feasible and economically viable. Lock-in has already largely occurred in HICs and MICs, where high-emitting infrastructure and other long-lived assets are costly to decommission (Rozenberg and Fay 2019). By contrast, these and other barriers are less entrenched in LICs. One way to avoid lock-in is for LICs to improve their food system efficiency and productivity. Agriculture value added in LICs is only $210 per hectare, whereas in MICs it is five times that at $1,100 per hectare.[9] In fact, most LICs and MICs are achieving less than half of their potential agricultural output, whereas HICs are achieving 70 percent. Another way for LICs to avoid lock-in would be to orient their agrifood systems toward low-emission food options. Such options cater to potential emissions trading schemes that tax GHG emissions and favor emerging retail markets for healthy foods. For example, global markets for certified organic products have grown by 102 percent between 2009 and 2019 (Willer et al. 2021). Still, only 1.5 percent of all agricultural land in 2019 was geared toward producing such foods (Willer et al. 2021).

Climate-smart agriculture (CSA) provides LICs an avenue to low-emission rural development. CSA is an integrated approach to managing agricultural production that can achieve the "triple win" (World Bank 2021) of the following: (1) economic gains, (2) climate resilience, and (3) lower GHG emissions. There are 1,700 combinations of production systems and technology that could be classified as CSA, with two-thirds pertaining to cropping systems for maize, wheat, rice, and cash crops. Only 18 percent of CSA technologies are for livestock systems, and just 2 percent are for aquaculture systems (Sova et al. 2018). Adopting CSA practices reduces emissions and contributes to economic development, a particularly helpful outcome in LICs. For example, in Zambia, the economic rate of return for such practices was 27–35 percent (World Bank 2019). CSA practices can also help LICs access carbon markets and benefit from emissions trading schemes. Furthermore, CSA can improve rural development. For example, developing renewable energy sources in agrifood systems has been shown to contribute to rural electrification and increased incomes in LICs (Christiaensen, Rutledge, and Taylor 2021).

Enabling Environment: The World Must Strengthen the Enabling Environment for the Agrifood System Transformation through Global and Country-Level Actions

Investments

Governments and businesses can remove barriers to agrifood sector climate investments through improved targeting, de-risking, accountability, and carbon markets. New business opportunities linked to agrifood systems transformation will likely be worth $4.5 trillion per year by 2030. However, investment risks and the high transaction costs of dealing with many small producers and small and medium enterprises pose challenges to investors and financial service providers. To facilitate the private sector's risk acceptance for decarbonization projects requires embracing higher risk-return profiles (Guarnaschelli et al. 2018; Santos et al. 2022) and building a pipeline of bankable projects that can secure financing (Apampa et al. 2021; IFC 2017). Part of the problem is that investors find short-term loans with immediate returns appealing but shy away from offering medium- and longer-term financial solutions (Apampa et al. 2021), which are necessary for food system transformation. Blended finance can overcome these concerns by leveraging public finance to reduce credit risks for private investments in climate action (OECD 2021). Increased corporate accountability can also make investments more effective (Santos et al. 2022) through government policies and business standards. Further, there are opportunities to expand innovative financing mechanisms, such as results-based climate finance and climate bonds. Incentivizing carbon credits and carbon taxes also offers opportunities to control the agrifood system's GHG emissions. At present, however, a relatively small share of the world's carbon markets and carbon pricing schemes apply to nonenergy agricultural emissions (despite covering a quarter of economy-wide emissions) (World Bank 2022). That said, carbon markets offer growing opportunities for carbon finance. The voluntary carbon market has grown considerably over the past five years, reaching approximately $2 billion in 2022 (Shell and BCG 2023), with expectations of further growth of from $5 billion to $50 billion by 2030, depending on many factors (Blaufelder et al. 2021). However, carbon markets and carbon pricing still suffer from several flaws. They are subject to "carbon panics," emissions exemptions are common, carbon markets are very complex, and emissions are difficult to measure. Carbon markets can overcome these flaws through greater transparency and carbon credit integrity.

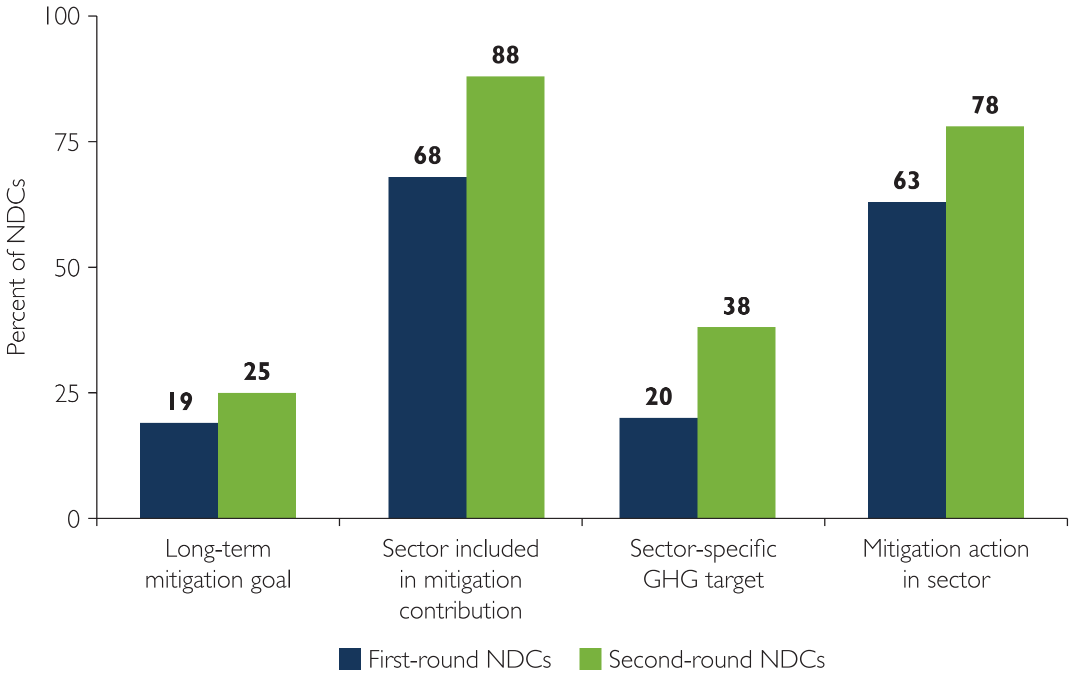
Incentives

Policy measures that could accelerate the transformation to a net zero argifood system are emerging. Two decades ago, HICs pioneered the development of mitigation policies for the agrifood sector, and in recent years, several MICs have followed suit. This movement toward agrifood sector mitigation is increasingly reflected in countries' NDCs. Currently, 147 of 167 second-round NDCs include AFOLU or agrifood systems in their mitigation commitments. This is a 20 percentage point increase from first- to second-round NDCs (figure O.10) (Crumpler et al., forthcoming).[10] The quality of these commitments has also improved: the share of NDCs with agriculture sector–specific GHG targets nearly doubled from 20 to 38 percent, and the share with specific agriculture-related mitigation actions increased from 63 to 78 percent (Crumpler et al., forthcoming). However, most NDC commitments are conditional on international support, including 92 percent of MIC NDC commitments in the AFOLU sector (Crumpler et al., forthcoming). This share is 100 percent for LICs but only 54 percent for HICs. Therefore, unfulfilled financial pledges have limited NDC implementation. Further, a lack of national policy coherence across sectors and within the agrifood sector also inhibits policy effectiveness. Improving this coherence and repurposing harmful subsidies toward agrifood system mitigation can deliver emissions reduction and multiple other benefits. A recent World Bank report shows that repurposing $70 billion of the world's approximately $638 billion in annual agriculture support during 2016–18 (Gautam et al. 2022; Voegele 2023) toward technologies that reduce emissions and improve productivity will boost crop production by 16 percent and livestock production by 11 percent. This would also increase national incomes by 1.6 percent, reduce the cost of healthy diets by 18 percent, and decrease overall agricultural emissions by 40 percent compared with business-as-usual 2020–40 levels (Gautam et al. 2022).

Information

Improving GHG monitoring can unlock climate finance. The measurement, reporting, and verification (MRV) of GHG emissions reductions is a complex, and often inaccurate, process

FIGURE 0.10 Agrifood Systems Have Become a Stronger Component of Nationally Determined Contributions



Source: World Bank based on data and original analysis carried out by the Food and Agriculture Organization for this report.
Note: Figure compares NDC mitigation contributions to the agrifood sector in first-round and second-round NDCs. GHG = greenhouse gas; NDCs = Nationally Determined Contributions.

(Toman et al. 2022). Nevertheless, MRV is important for accessing carbon markets, assessing emissions reduction progress, and tracking project performance, among other reasons. However, several constraints are holding back the development of robust MRV systems. They include limited budgets, data availability, technical capacity among practitioners, and infrastructure to monitor emissions. That said, a growing number of international organizations are helping countries build MRV capacity to track Paris Agreement targets (WRI 2024). There are three main technologies that assist practitioners in measuring agricultural emissions: (1) remote-sensing technologies, (2) ground-based sensors, and (3) ecosystem carbon flux measurements (Dhakhwa et al. 2021). Likewise, emerging digital technologies offer new opportunities to improve MRV and lower its costs. Digital technologies enable faster and easier access to information for all players in the agrifood value chain. This information flow incentivizes farmers to adopt production tools and systems that can mitigate climate change, contribute to environmental sustainability, and optimize productivity (Schroeder, Lampietti, and Elabed 2021).

Innovation

Innovative practices for reducing agrifood emissions are expanding and becoming cost-effective, though there is a desperate need for more research and development (R&D) to continue this trend. Nascent, innovative mitigation technologies could greatly contribute to emissions reductions and improved productivity in the agrifood system (Alston et al. 2011). These technologies include using chemical methane inhibitors, feed additives from red seaweed, crop roots to sequester carbon, indoor farming methods, precision machinery, plant-based meats, lab-grown protein, and other protein sources. Moreover, some of these technologies are already providing viable solutions that are affordable. A conservative estimate is that innovative agrifood technologies that are cost-effective in the near term could reduce 2 $GtCO_2eq$ per year. R&D can drive many of these innovative technologies by further reducing costs and making them competitive with fossil fuel options (Bosetti et al. 2009). The Paris Agreement specifically recognizes the importance of R&D and calls for "collaborative approaches" to enhance and produce climate-related technologies.[11] Returns from R&D expenditures are high for both developing and developed countries: a 1 percent increase in R&D investment yields internal rates of return of 46 percent in developed countries and 43 percent in developing countries (Alston et al. 2000). However, R&D spending in the agrifood sector remains minimal.

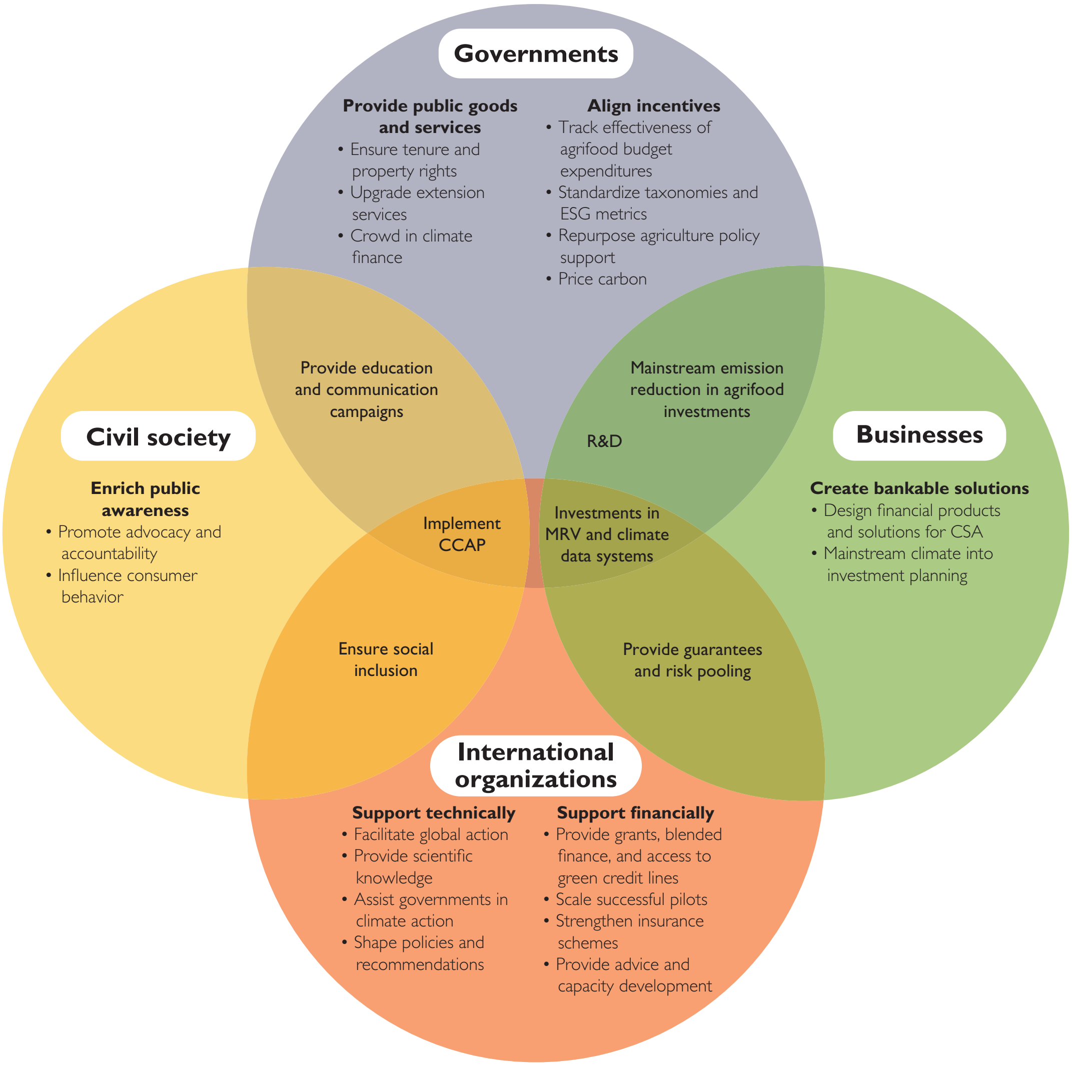
Institutions

Climate institutions will govern the agrifood system's transformation to a net zero model. The global institutional architecture supporting climate action in the agrifood system is complex and operates at various levels (figure O.11). This architecture includes international frameworks to aid developing countries in acquiring finance, technologies, and knowledge to address climate change challenges. For example, one of UNFCCC's mandates is to promote and facilitate environmentally sound technology transfers to these nations, ensuring effective climate change mitigation and adaptation. Likewise, at the UN Climate Change Conference in 2009 (COP15), HICs pledged to mobilize $100 billion annually to support developing countries in their climate actions. Growing steadily since 2015, HICs provided $89.6 billion in total climate finance in 2021. This was a 7.5 percent increase from 2020 but still $10.4 billion short of the goal (OECD 2023). Nearly half of this total went to the energy and transport sectors, and only 8 percent went to agriculture, forestry, and fishing. Similarly, multilateral and bilateral donors are positioning themselves to lead in climate action but still lag in the agrifood transformation. For example, multilateral development banks reached a record of nearly $100 billion of climate financing in 2022 but allocated only $2.3 billion to mitigation in agrifood-related sectors. That said, agrifood mitigation has increasingly become a part of climate negotiations and NDCs, with a full day dedicated to food, agriculture, and water for the first time at the UN Climate Change Conference in 2023 (COP28). National and subnational institutions also have important roles to play in agrifood system mitigation, but this theme is often fragmented across various institutions that lack policy coherence, making coordinated action difficult. Creating "green jurisdictions," where subnational jurisdictions come together around climate action, can help overcome many subnational divisions. However, in many cases, these jurisdictions are also fragmented or focus on competing or parallel issues (Khan, Gao, and Abid 2020).

Inclusion

Governments and civil society must work together to ensure that the agrifood system transformation is equitable, inclusive, and just. Poorly targeted mitigation policies could raise production costs and food prices in the short term, which accounts for a larger share of household budgets for poor people than for the well-off, leading to unequal burden sharing. Therefore, a just transition in the agrifood system means reducing emissions while ensuring jobs, good health, livelihoods, and food security to vulnerable groups and smallholder farmers (Baldock and Buckwell 2022; Tribaldos and Kortetmäki 2022). The transition must

FIGURE O.11 Governments, Businesses, Civil Society Groups, and International Organizations All Have Roles to Play in Scaling Climate Action



Source: Original figure for this publication.
Note: CCAP = Climate Change Action Plan; CSA = Climate-Smart Agriculture; ESG = environmental, social, and governance; MRV = measurement, reporting, and verification; R&D = research and development.

achieve procedural, distributive, and restorative justice to avoid the adverse health, social, economic, and environmental impacts from previous food system changes (Tribaldos and Kortetmäki 2022). Ample stakeholder engagement can help guarantee procedural justice or process legitimacy. Meanwhile, benefit sharing, especially in agrifood sector employment, can ensure distributive justice. For example, the agrifood system transformation will likely create new types of employment, and it is important for governments to facilitate this transition from farm work to higher-quality nonfarm jobs through skills training (Rotz et al. 2019) and mobility assistance (Fuglie et al. 2020). Likewise, the informal jobs sector can buffer the agrifood sector from job losses and food insecurity and assist with short-term job placement. The transformation must also ensure restorative justice by supporting groups that historically have not benefited from the agrifood system, such as smallholder farmers. To do so, governments should partner with affected communities and local governments to deliver local social empowerment through the agrifood system.

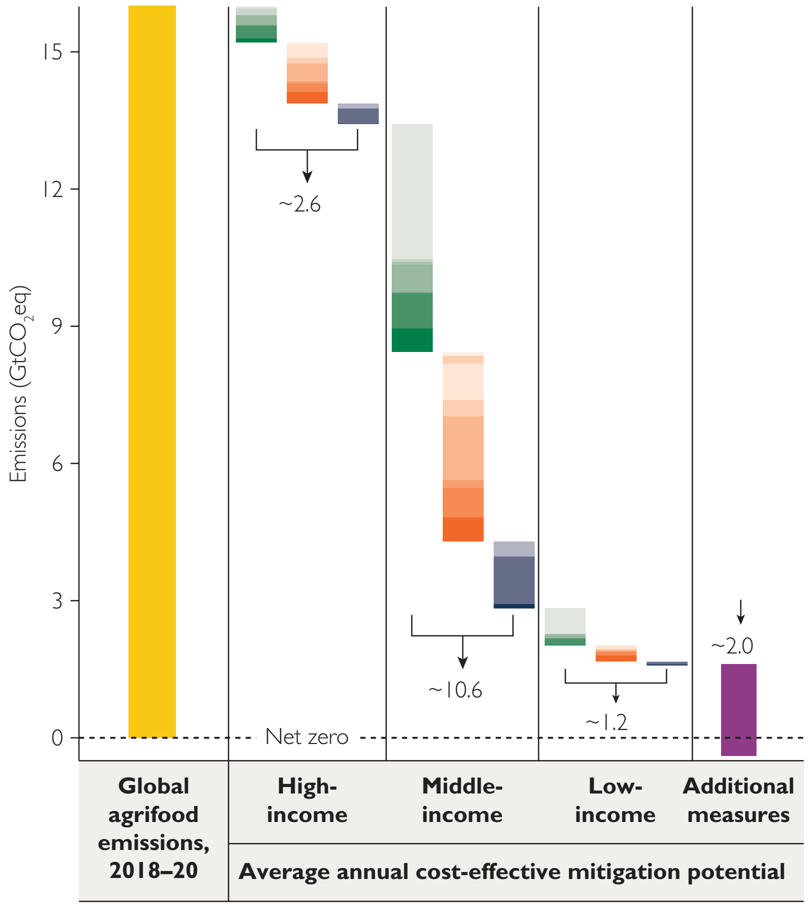
The Recipe Is Doable

Solutions for transforming the agrifood system to net zero emissions are available and affordable. Over the past three decades, the food system has witnessed remarkable successes. Agricultural producers have dramatically increased their output through more efficient resource use and superior technologies and practices. Moreover, conditions to propel the transformation into the future are in place. There are new technologies, an engaged private sector, heightened consumer awareness, and advanced digital tools. Moreover, there are no intrinsic trade-offs between climate action and the goals of income generation or food security. With the right adaptation and mitigation measures, it is entirely possible to diminish agrifood system emissions while simultaneously bolstering economies, supporting farmers, and feeding the planet. From a pragmatic perspective, the most compelling aspect is that an agrifood system transformation is affordable now and can improve the trade competitiveness of countries specializing in low-emission agrifood practices. Figure O.12 shows that there are many cost-effective or cost-saving mitigation options available for the agrifood system that can cover all 16 gigatons of the agrifood system's annual GHG emissions, which is about four times Europe's total annual emissions. Consequently, the estimated costs of mitigating the agrifood system's climate impact are just a fraction—roughly one-tenth—of the projected global energy investments for 2023 and less than 5 percent of fossil fuel subsidies, which reached $7.1 trillion in 2022 (Black et al. 2023).

The recipe for achieving net zero emissions in the agrifood system entails country-specific and global enabling efforts. HICs should lead the way. They can do this by curbing energy emissions, aiding developing nations in their shift to low-emission development pathways, and repurposing subsidies away from high-emission and environmentally destructive foods to curb their demand. Likewise, MICs have an outsize role to play. They generate two-thirds of global agrifood emissions and could cut most of them by focusing on lowering methane emissions from rice and livestock production, harnessing the potential of soils to sequester carbon, and shifting to cleaner, more efficient, and circular approaches to the agrifood system's pre- and post-production activities. LICs can bypass the high-emissions development path taken by HICs and MICs for a greener, more competitive development path. LICs have an opportunity to make smart choices now that will benefit them in the long term by avoiding a high-emissions development path that would be costly to reverse later. They should prioritize and monetize the protection and restoration of carbon-rich forests and other ecosystems, improve agrifood systems' efficiency, and promote climate-smart practices, thereby achieving a triple win of increased productivity, climate resilience, and reduced emissions. Empowering countries to take these actions at scale requires a conducive enabling environment, both globally and within countries. Governments, businesses, consumers, and international organizations must work together to (1) generate investments and create incentives through policy, (2) improve information and innovation to drive the agrifood system transformation into the future, and (3) leverage institutions to facilitate these opportunities while ensuring the inclusion of stakeholders and marginalized groups (figure O.13).

FIGURE O.12 By 2050, Cost-Effective Mitigation Action in the Agrifood System Transformation Can Reduce Greenhouse Gases by Over 16 Gigatons a Year, Achieving Net Zero Emissions

a. All countries can reduce emissions cost-effectively now, and the largest potential is in MICs



b. HICs, MICs, and LICs can follow different pathways to reduce their emissions

	Mitigation action	High-income	Middle-income	Low-income
	Land use			
Protect	Reduced deforestation	1.8	28.0	45.0
	Reduced peatland degradation	5.5	0.5	0.7
	Reduced mangrove conversion	0.3	0.6	0.2
Manage	Forest management	8.5	5.8	6.0
	Grassland, fire management	0.1	0.1	1.4
Restore	Afforestation, reforestation	11.2	7.3	11.4
	Peatland, mangrove restoration	3.2	4.8	0.2
	Total	**30.6%**	**47.1%**	**64.8%**
	On-farm			
Livestock	Enteric fermentation	1.0	0.6	0.7
	Manure management	2.5	0.3	0.1
Rice	Rice cultivation	0.2	1.5	0.3
Integrated production	Agroforestry	9.5	7.5	6.4
	Bioenergy	4.7	3.5	1.0
Soils	Biochar from crop residues	15.5	13.0	2.9
	Nutrient management	1.7	1.7	0.1
	Soils in croplands	7.4	6.1	6.6
	Soils in grasslands	9.8	5.0	10.3
	Total	**52.1%**	**39.2%**	**28.4%**
	Pre- and post- production			
Demand side	Reduced food waste	4.2	3.1	1.2
	Shift diets	13.1	9.8	4.3
	Clean cooking	—	0.8	1.3
	Total	**17.3%**	**13.7%**	**6.8%**

Sources: World Bank based on data from Roe et al. 2021 and World Bank 2024.

Note: Panel a shows by country income group the cost-effective annual mitigation potential for reducing emissions from land use, on-farm, and pre- and post-production process. Additional measures include technologies and innovations that can deliver cost-effective emissions reductions by 2030. These include: nitrous oxide abatement in fertilizer production; plant-based proteins; low-emission energy sources for on-farm machinery; improved on-farm energy-efficiency; improved livestock feed digestibility and feed additives; and increased use of renewable energy in cold chains. Details on these measures are described in chapter 4. Average annual mitigation potential for land-based mitigation measures for high-, middle-, and low-income countries are based on 2020-2050 scenarios. $GtCO_2eq$ = gigatons of carbon dioxide equivalent. HICs = high-income countries; LICs = low-income countries; MICs = middle-income countries; — = not available.

FIGURE O.13 The Recipe for Creating an Enabling Environment Allows Countries in All Income Groups to Contribute to Transforming Agrifood Systems to Achieve Net Zero Emissions

Relative share of cost-effective opportunities by country income group

	Sustainable land use — Ecosystems			Clean inputs		Efficient and productive farms — Low emissions		Efficient and productive farms — Sequestration			Clean post-production	Consumer behavior		
	Protect	Manage	Restore	Fertilizer	Energy	Rice	Livestock	Agroforestry	Bioenergy	Soils		Clean cooking	Healthy diet	Food waste
High-income	Low	Medium	Medium	Medium	Medium	Low	Low	Medium	Low	High	Medium	Low	Medium	Low
Middle-income	High	Low	Medium	Medium	Medium	Low	Low	Low	Low	High	Medium	Low	Medium	Low
Low-income	High	Low	Medium	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low

Paris Agreement climate targets

Drivers for transformation

- **Climate and environment**
- **Society and economy**
- **Agrifood system**

Six "I's" — **Investments • Incentives • Information • Innovation • Institutions • Inclusion**

Source: Original figure for this publication.
Note: Figure summarizes the distribution of cost-effective mitigation potential by income group across 14 key areas of intervention related to sustainable land use, clean inputs, efficient and productive farms, clean post-production, and consumer behavior (top part of the table). The relative share of cost-effective mitigation potential is indicated as follows: low: <8 percent; medium: 8-16 percent; high: >16 percent.

Moving Forward

This recipe lists the required ingredients for transforming the global agrifood system to achieve net zero emissions. These cost-effective mitigation practices and enabling actions should be implemented immediately and concurrently by all countries. That said, this report has shown where different countries—high-, middle-, and low-income countries—have the greatest opportunities to reduce global agrifood emissions. This potential was determined on the basis of where emissions concentrations were highest or fastest growing and the relative costs of mitigating those concentrations. Put simply, this report guides countries toward agrifood system mitigation efforts that give the most bang for the buck. Consequently, this should be a country-driven approach in which HICs, the World Bank, and other bilateral or multilateral donors provide the knowledge and finance to enable public and private national actors to contribute to this transformation. More immediately, the World Bank and its development partners can build on this report by filling remaining knowledge gaps and carrying out similar analyses at the country level.

Notes

1. World Bank calculations using IEA and FAOSTAT data covering 2018–20. Accessed in 2023.
2. World Bank/FAOSTAT 2023 databases.
3. Authors' estimates, calculated using benefits corresponding to 6 of the 10 critical transformations that directly contribute to agrifood mitigation, as identified in FOLU 2020.
4. This is the selected threshold for economic mitigation potential in the IPCC's AR6 Chapter on AFOLU (Nabuurs et al. 2022) and is the high estimate for the World Bank's shadow price of carbon in 2030. It is also policy relevant, given that it falls within the 2030 carbon price corridor based on the recommendations of the High-Level Commission on Carbon Prices, adjusted for inflation.
5. Shift to sustainable health diets is defined in Roe et al. 2021 as emissions reductions from diverted agricultural production (excluding land-use change) from the adoption of sustainable healthy diets: (1) maintain a 2,250 calorie per day nutritional regime; (2) converge to healthy daily protein requirement, limiting meat-based protein consumption to 57 grams per day; and (3) purchase locally produced food when available. Carbon sequestration in agriculture includes (1) agroforestry, (2) biochar from crop residues, (3) soil organic carbon in croplands, and (4) soil organic carbon in grasslands.
6. In the decade 2010–19, energy efficiency increased by 1.9 percent, far lower than 3.2 percent, the rate needed to achieve the Sustainable Development Goal 7.3 target.
7. See calculations for this example at https://energyaccess.duke.edu/catalyzing-climate-finance (The James E. Rogers Energy Access Project at Duke).
8. World Bank, Development Indicators, "Forest area (% of land area)—Sub-Saharan Africa (accessed 2023), https://databank.worldbank.org/source/world-development-indicators.
9. World Bank, World Development Indicators (accessed 2023), https://data.worldbank.org/indicator.
10. First-round NDCs refer to intended nationally determined contributions and NDCs submitted by Parties to the UNFCCC as of July 29, 2016. Second-round NDCs refer to the latest NDCs submitted by Parties to the UNFCCC as of June 30, 2023. This includes new/updated NDCs as well as first NDCs (if new/updated NDCs were not submitted).
11. In accordance with Article 10, Paragraph 5, of the Paris Agreement.

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The global agrifood system has been largely overlooked in the fight against climate change. Yet, greenhouse gas emissions from the agrifood system are so big that they alone could cause the world to miss the goal of keeping global average temperatures from rising above 1.5 centigrade compared to pre-industrial levels. Greenhouse gas emissions from agrifood must be cut to net zero by 2050 to achieve this goal.

Recipe for a Livable Planet: Achieving Net Zero Emissions in the Agrifood System offers the first comprehensive global strategic framework to mitigate the agrifood system's contributions to climate change, detailing affordable and readily available measures that can cut nearly a third of the world's planet-heating emissions while ensuring global food security. These actions, which are urgently needed, offer three additional benefits: improving food supply reliability, strengthening the global food system's resilience to climate change, and safeguarding vulnerable populations.

This practical guide outlines global actions and specific steps that countries at all income levels can take starting now, focusing on six key areas: investments, incentives, information, innovation, institutions, and inclusion. Calling for collaboration among governments, businesses, citizens, and international organizations, it maps a pathway to making agrifood a significant contributor to addressing climate change and healing the planet.

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