

FOOD AND CLIMATE CHANGE INFOGUIDE

The food system contributes more than 30% of the heat-trapping gases emitted by human activities globally each year.¹ If those emissions continue to increase at their current pace, meeting the Paris Agreement's 1.5°C (2.7°F) goal would be impossible even if non-food system emissions fell to zero immediately.²

Food and climate impacts go both ways. Climate change creates significant risks to the food system, with rising temperatures and changing weather patterns threatening enormous damage to crops, supply chains and livelihoods in the decades ahead.³

The food system touches everyone. Hundreds of millions of people work in agriculture and other aspects of food production, with the highest percentages in developing countries.⁴ More than a billion people, mostly women, prepare food as a central part of everyday activities.⁵ Food choices play a central role in human health and culture.

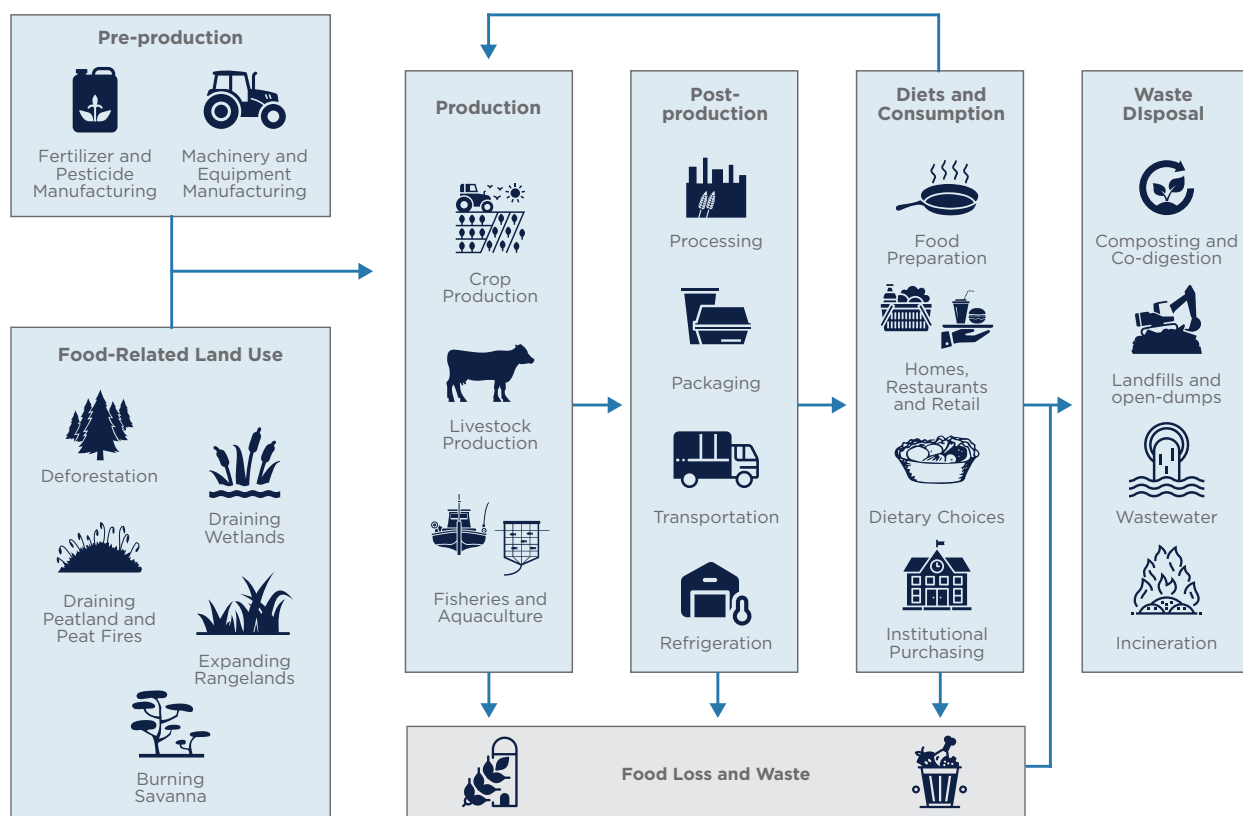
This InfoGuide provides background on the food system (Part 1), climate change (Part 2), the impact of the food system on climate change (Part 3) and the impact of climate change on the food system (Part 4). The final section (Part 5) presents strategies for reducing emissions from the food system and improving the resilience of the food system to climate change.

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1. Food System Overview

The food system spans a vast array of activities—from land clearing to fertilizer manufacturing to crop growing to livestock production to fish harvesting to meal preparation to landfill management. It includes food production, transport, processing, packaging, storage, consumption and disposal.

Figure 1: A simplified diagram of food system activities⁶



Source: All icons are sourced from The Noun Project under the Creative Commons BY 3.0 "Attribution License." From top left to bottom right: Fertilizer by Syaiful Amri, Tractor by Olivier, Forest by Nesdon Booth, Wetland by Iconathon, Moss by Laymik, Thick Grass by Hamish, Savanna by Hamish, Farming by ProSymbols, Cow by Alexandr Lavreniuk, Boat by Amethyst Studio, Aquaculture by Angelo Troiano, Grains Silo by Ben Davis, GMO by Stephanie Wauters, Food Container by dDara, Transport by Prianka, Temperature by Andrejs Kirma, Cooking by Erik Arndt, Grocery by Iconixar, Fast Food by Kristina Margaryan, School Building by Siipkan Collective, Waste by Priyanka, Compostable by Luca Reghellin, Excavator on Landfill by Peter van Drie, Wastewater by Mavadee, and Incineration by Eucalypt.

Economic Value

A 2019 World Bank study estimated that the food system contributes \$8 trillion per year to gross domestic product (GDP)—roughly 10% of the global economy.⁷

- The food system supports the livelihoods of over 1 billion people.⁸
- In general, agriculture's share of the economy declines as countries grow wealthier.
 - In low-income countries, agriculture contributes 22% of GDP on average.
 - In middle-income countries, agriculture contributes 8% of GDP on average.
 - In high-income countries, agriculture contributes 1% of GDP on average.⁹
- In 2019, the export value of all food products traded internationally was over \$1.8 trillion.¹⁰



Land Use

Roughly 35% of the world's total land area excluding Antarctica is used for agriculture.¹¹

- Of the total land area used for agriculture, roughly two-thirds are pastures and rangelands for livestock grazing and production.¹²
- Overgrazing is the number one cause of land degradation and desertification globally, causing about 35% of human induced soil degradation.¹³
- The vast majority of tropical deforestation (75%–90%) stems from expanding agricultural land for the production of commodities such as beef, soy and palm oil. Deforestation is occurring most rapidly in Latin America, followed by Africa.¹⁴



Energy Use

The food system and energy system are deeply intertwined. Every part of the food system uses energy. Roughly 30% of global energy consumption comes from the food system.¹⁵

- Most energy used in the food system comes from fossil fuels, although renewable energy's share is rising. Many agricultural production areas have good access to solar and wind resources.¹⁶
- Roughly 5% of global natural gas demand is for the synthesis of nitrogen fertilizers.¹⁷



Main Crops

Over 40% of human calories come directly from three crops: rice, wheat and maize.¹⁸ These three crops account for roughly two-thirds of all human calories (including rice, wheat and maize used as feed for livestock consumed by humans).¹⁹ Soybeans have the fourth largest production area of all crops globally.²⁰



- In 2018, Asia consumed roughly 88% of the world's rice and 59% of the world's wheat.²¹
- The US produces the most maize in the world.²² In 2019, about a third of corn produced in the US was used for ethanol production, one-third for domestic animal feed and another third for domestic consumption and exports.²³
- In 2019/2020, Brazil led the world with 37% of global soy production, followed closely by the US with 36%. About 70% of global soy production is processed into protein meal for animal feed.²⁴



Livestock Production

In 2018, global livestock production neared 24 billion chickens, 1.5 billion heads of cattle, 1.2 billion sheep, 1 billion goats and 980 million pigs.²⁵

- Between 2008 and 2018, the number of chickens raised annually grew 25%—by far the fastest growing livestock group. The number of goats grew by 16%, sheep by 10%, cattle by 5% and pigs by 4%. (The human population grew roughly 12% during this period.)²⁶
- China produces nearly half of global pig meat. The United States is the world's largest producer of beef and poultry.²⁷



Fisheries and Aquaculture

In 2017, fish provided 17% of global animal protein intake and 7% of all protein consumed.²⁸

- In 2018, 54% of total fish production came from capture fisheries, while 46% came from aquaculture.²⁹
- Global fish consumption between 1961 and 2017 grew faster than all other animal foods.³⁰



Food Preparation

More than 2.6 billion people lack access to clean cooking technologies, depending on biomass, kerosene or coal as their primary cooking fuel.³¹

- In sub-Saharan Africa, more than 80% of households lack access to clean cooking. In India, roughly half of households lack such access.³²
- Household air pollution—primarily from cooking smoke—is associated with nearly 2.5 million premature deaths annually.³³ In many developing countries, the burden of collecting fuel for cooking falls disproportionately on women and children, who also face greater exposure to pollutants from cooking smoke.³⁴



Undernourishment and Obesity

The food system is plagued by distributional inequities.

- There are enough protein, carbohydrates and fat produced each year to meet the dietary needs of every person on Earth.³⁵ Yet nearly 2 billion people suffered from



undernourishment in 2019.³⁶ Of those 2 billion, 690 million people—9% of the world's population—faced hunger.³⁷

- At the same time, another 2 billion adults are overweight or obese.³⁸ The global prevalence of diabetes has nearly doubled in the past 30 years and is predicted to continue increasing due to dietary changes.³⁹
- Within many countries, there are problems with undernourishment and obesity simultaneously.⁴⁰
- The COVID-19 pandemic has significantly increased the number of hungry people globally. In addition, some comorbidities that increase the risk of hospitalization and death from COVID-19 -- including diabetes, hypertension and heart disease -- are associated with unhealthy high-calorie diets (such as those rich in refined carbohydrates, added sugar, saturated fats and red meat).⁴¹



Food Loss and Waste

Roughly one-third of food that is produced is never consumed. This food is either lost in the field on the way to the consumer or wasted in institutional settings, stores, homes or restaurants.⁴²

- About 30% of all food loss and waste occurs at the production stage.⁴³
- In 2016, approximately 14% of global agricultural production was lost during postharvest and distribution.⁴⁴
- Roughly 8% of the world's annual food supply is wasted by households and restaurants as they prepare and dispose of their daily meals.⁴⁵
- Over 10% of the world's total energy consumption is used to provide food that is lost or wasted.⁴⁶



Biodiversity

The conversion of natural forests to produce food commodities is the single greatest driver of habitat loss globally.⁴⁷

- Agriculture is estimated to drive about 70% of biodiversity loss and 80% of deforestation globally.⁴⁸
- The food consumed in one country can have an impact on the biodiversity of another. For example, 95% of the impact of Swiss food consumption is felt abroad, with coffee, cocoa and palm oil plantations all contributing to habitat loss in other countries.⁴⁹

2. Climate Change Overview

Atmospheric concentrations of heat-trapping gases are now higher than any time in human history. This is changing the Earth's climate.⁵⁰

- The principal heat-trapping gases are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and fluorinated gases (such as HFCs and SF₆). These are also commonly referred to as greenhouse gases.
- Carbon dioxide is responsible for roughly 76% of the warming impact of these gases globally. Methane is responsible for roughly 16%, nitrous oxide for 6% and fluorinated gases for 2%.⁵¹
- The Intergovernmental Panel on Climate Change (IPCC) finds with very high confidence that atmospheric concentrations of heat-trapping gases are now higher than any time in at least 800,000 years.⁵²
- The Earth's average surface temperature has risen about 1.14°C (2.05°F) since the late 19th century.⁵³
- The seven warmest years on record have been the past seven years.⁵⁴

Human activities are the principal cause of the buildup of heat-trapping gases in the atmosphere. Those activities include burning fossil fuels (coal, oil and gas) and land use change.⁵⁵

- Roughly 25% of global emissions come from electricity and heat production, 21% come from industry and 14% come from transport.⁵⁶
- Roughly 24% of global emissions come from agricultural, forestry and other land use.⁵⁷

The impacts of a changing climate are being felt across the globe.

- Storms and heat waves have increased in frequency and intensity in recent decades.⁵⁸
- Warming air temperatures and droughts made more likely by climate change have directly contributed to increased fire risk in many parts of the world. Changes in climate over the past 30 years are associated with a doubling of extreme fire weather conditions in California.⁵⁹

The world is not on a path to meet globally-agreed climate change goals.

- More than 190 nations have adopted the Paris Agreement, which calls for “holding the increase in global average temperature to well below 2°C (3.6°F) above pre-industrial levels” and “pursuing efforts to limit the temperature increase to 1.5°C (2.7°F) above pre-industrial levels.”⁶⁰
- However, policies currently in place around the world would result in a global average temperature increase of 2.9°C (5.2°F) by 2100, and many policies to limit emissions are not being fully implemented.⁶¹



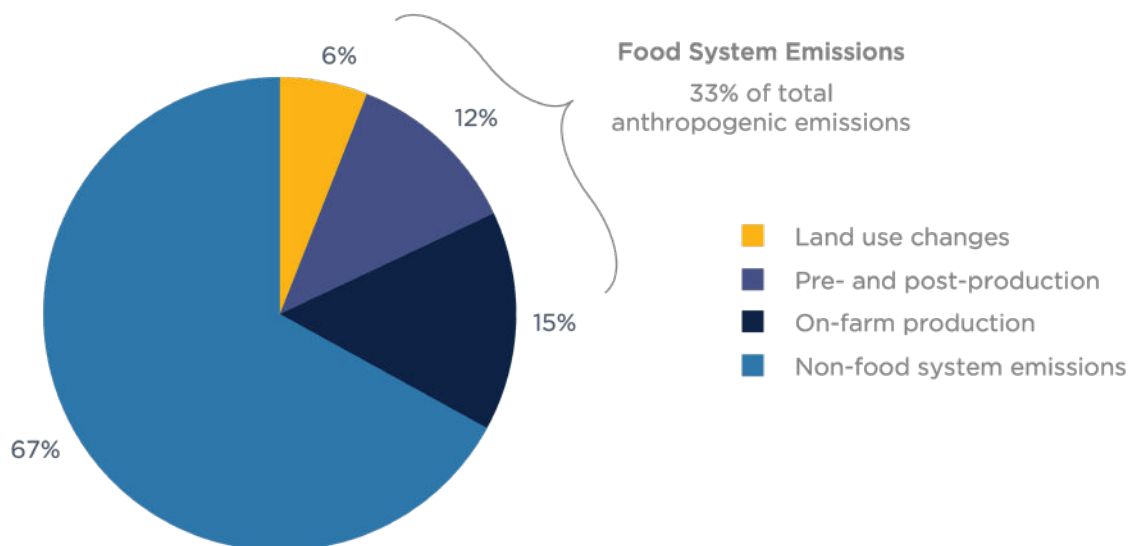
Billions of people face extraordinary risks unless the buildup of heat-trapping gases in the atmosphere slows and then reverses in the decades ahead.⁶²

- Those risks include more severe and frequent storms, floods, droughts and heat waves, as well as sea level rise.⁶³
- Climate change is expected to increase heat-related mortality rates and the incidence of lung and heart disease associated with poor air quality. Higher temperatures and more frequent flooding events caused by climate change contribute to the spread of infectious and vector-borne communicable diseases such as dengue, malaria, hantavirus and cholera.⁶⁴

3. Food System Impacts on Climate Change

The IPCC estimates that the food system is responsible for 21%–37% of heat-trapping gases emitted by human activities globally.⁶⁵ A study published in *Nature* in March 2021 estimates that the food system is responsible for a third of heat-trapping gases emitted globally.⁶⁶ Work from the authors of this paper confirms that estimate.⁶⁷

Figure 2: Food system emissions, by category, as a percentage of total anthropogenic emissions (2018).



Source: Data from F. N. Tubiello et al., "Greenhouse gas emissions from food systems: building the evidence base," *Environmental Research Letters*, <https://doi.org/10.1088/1748-9326/ac018e>.



Food-Related Forestry and Land Use Change

Forestry and land use changes related to the food system are responsible for between 5% and 14% of all anthropogenic emissions of heat-trapping gases.⁶⁸

- Agriculture is responsible for approximately three-quarters of global emissions associated with forest loss.⁶⁹
- In 2018, agricultural land use and land use change were responsible for emissions of nearly 4 Gt CO₂-eq (roughly 8% of global emissions of heat-trapping gases). This included emissions from cutting forests, burning savanna and draining peatlands.⁷⁰



Pre-Production Emissions

Pre-Production emissions include emissions associated with fertilizer and pesticide manufacturing and the production of farm equipment such as tractors and irrigation pumps. There is currently a dearth of country-level data on emissions from these sources.

On-Farm Emissions

Agriculture is a major source of methane and nitrous oxide emissions. Roughly half of anthropogenic methane emissions and three-quarters of anthropogenic nitrous oxide emissions come from within the farm gate.⁷¹



Livestock Emissions

Roughly 15% of global emissions of heat-trapping gases come from livestock.⁷²

- Cattle are the main source of global livestock emissions (65%–77%).⁷³
- In 2018, enteric fermentation (part of the digestive process of ruminant animals such as cattle, sheep, goats and buffalo) was responsible for 2.1 Gt CO₂-eq of methane emissions—the largest component of farm-gate emissions and roughly 4% of global emissions of heat-trapping gases.⁷⁴
- In 2018, livestock manure was responsible for 1.0 Gt CO₂-eq of nitrous oxide emissions—roughly 2% of global emissions of heat-trapping gases.



Crop Emissions

Fertilizers, rice paddies and on-farm energy use are each significant emissions sources.

- In 2018, synthetic fertilizers were responsible for 0.7 Gt CO₂-eq of nitrous oxide emissions—roughly 1.4% of global emissions of heat-trapping gases.⁷⁵
- In 2018, rice cultivation was responsible for 0.5 Gt CO₂-eq of methane emissions—roughly 1% of global emissions of heat-trapping gases.⁷⁶
- In 2018, on-farm energy use contributed approximately 1.0 Gt CO₂-eq of emissions, representing about 2% of global emissions.⁷⁷





Dietary Choices

Dietary choices play a large role in determining the amount of heat-trapping gases emitted from the food system.

- In general, animal-based food products are associated with higher emissions than plant-based foods.⁷⁸
- Beef generates the highest emissions of heat-trapping gases per kilogram (kg) of commodity produced, outpacing milk, pork, eggs and all crops.⁷⁹
- According to the best available estimates, the food items with the highest CO₂ emissions per kg are the following:⁸⁰
 - Beef: 60 kg CO₂-eq per kg
 - Lamb and mutton: 24 kg CO₂-eq per kg
 - Cheese: 21 kg CO₂-eq per kg
- In general, CO₂-equivalent emissions from crop products are 10–50 times lower than most animal products, per kg of product.⁸¹
- In general, animal products produce more CO₂ per unit of protein as well. The emissions per 100 grams of protein for several popular food sources are listed below:⁸²
 - Beef: 49.9 kg CO₂-eq
 - Cheese: 19.8 kg CO₂-eq
 - Poultry: 5.7 kg CO₂-eq
 - Eggs: 4.2 kg CO₂-eq
 - Grains: 2.7 kg CO₂-eq
 - Soybeans: 2.0 kg CO₂-eq
 - Nuts: 0.26 kg CO₂-eq

Post-Production Emissions

Roughly 45% of total energy use by the food sector is attributable to food processing and distribution.⁸³



Refrigeration

- Nearly 40% of all food that is produced requires refrigeration.⁸⁴
- The food sector cold chain is responsible for almost 2% of global anthropogenic greenhouse gas emissions.⁸⁵





Transportation

Food transportation is responsible for roughly 6% of all food system emissions globally. (In the United States, the figure is 11%).⁸⁶

- About 60% of the miles that food products travel globally are via water.⁸⁷
- Relatively little food is transported by air freight. However, perishable foods that are shipped internationally by air have a carbon footprint between 5 times and 20 times more than if they were transported by road and rail transport, respectively.
- Domestic food transport alone contributed about 0.5 Gt CO₂-eq emissions in 2018, representing about 1% of global emissions.⁸⁸



Food Preparation

In developing countries, cooking often utilizes traditional low-efficiency stoves, which generate significant negative impacts on both climate and health.⁸⁹

- Solid-fuel cooking in developing countries is associated with greenhouse gas emissions of 0.5–1.2 Gt CO₂-eq per year, representing roughly 1.5%–3% of total anthropogenic emissions.⁹⁰ This figure does not include emissions associated with cooking using electricity and LPG—which characterizes much of the cooking in developed countries—or renewable sources such as biogas and solar.
- Although both electric and gas cookstoves generate fewer emissions than solid-fuel cookstoves, there are still significant differences between the two. For instance, the greenhouse gas emissions associated with cooking with a gas stove can be roughly 6 times higher than with an electric stove.⁹¹



Food Loss, Waste and Disposal

Per capita rates of food loss and waste have been rising globally, and the emissions associated with food loss and waste are accelerating in parallel.

- Over 10% of the world's total energy consumption is used to create food products that are never consumed, and roughly 8% of anthropogenic greenhouse gas emissions result from producing, shipping, storing and processing food that is lost or wasted.⁹²
- The methane generated from solid food waste in landfills is responsible for roughly 2% of all anthropogenic greenhouse gas emissions.⁹³



4. Climate Change Impacts on Food Systems

Impact on Crop Yields

The buildup of heat-trapping gases in the atmosphere suppresses global average crop yields. This is due to the effects of high temperatures on growing periods and critical growth stages, more severe droughts and storms, the spread of pests, and other factors.⁹⁴

- Between 1981 and 2010, climate change lowered global average yields of maize by 4.1%, wheat by 1.8% and soybeans by 4.5% as compared to what yields would have been without climate change.⁹⁵
- Climate change may lead to crop yield increases in some temperate regions in the near term, in part because greater CO₂ concentrations lead to enhanced photosynthesis in some crops (the CO₂ fertilization effect).⁹⁶ However, in the longer term, all agricultural regions will suffer.⁹⁷
- Climate change is projected to have the most dramatic negative impacts on crop yields in the tropics and subtropics, where hundreds of millions of smallholder farmers live and work.⁹⁸
- The majority of crop models show declining global crop yield over the 21st century at a 2°C (3.6°F) increase in global warming, with direct yield losses occurring in some crops in the near term and higher yield losses in almost all crops likely to occur in the second half of the century.⁹⁹

Impact on Nutritional Content and Health

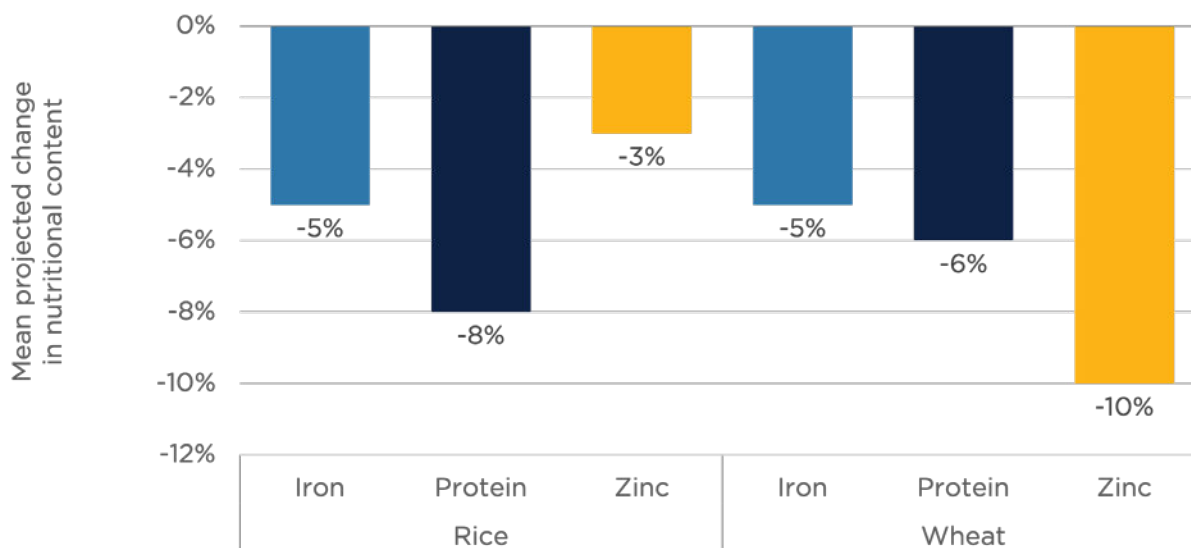
Increasing concentrations of heat-trapping gases in the atmosphere have negative impacts on the nutritional quality of globally important crops.

- Decreases in protein content and micronutrients have been found for crops grown under high CO₂ conditions.¹⁰⁰

Such changes could have a negative impact on global health, as an estimated two billion people already suffer from dietary deficiencies of zinc and iron.¹⁰¹



Figure 3: Estimated impact of elevated atmospheric CO₂ on the nutritional content of rice and wheat



Source: Data are mean estimates from Samuel S. Myers et al., "Increasing CO₂ Threatens Human Nutrition," *Nature* 510, no. 7503 (June 2014) at pp. 139-42.

Impact on Food Security

Climate change is likely to increase malnutrition and lead to less healthy diets in lower- and middle-income countries.¹⁰²

- Subsistence farmers are particularly vulnerable to climate change. Many are located in the tropics, rely entirely on rainwater and have relatively little adaptive capacity.¹⁰³ Nearly two-thirds of the labor force living in extreme poverty work in agriculture.¹⁰⁴
- Climate change may have a severe impact on childhood nutrition in vulnerable populations. By one estimate, climate change could increase childhood stunting by 23% in sub-Saharan Africa and up to 62% in South Asia, after factoring in population growth, food price increases and the potential impacts of climate change on cereal yields.¹⁰⁵
- The climate risk for subsistence farmers in sub-Saharan Africa is borne disproportionately by women. This is in part due to significant male out-migration from rural villages.¹⁰⁶






5. Mitigation and Adaption Strategies

Dozens of strategies can help reduce emissions of heat-trapping gases from the food system and improve the resilience of the food system to climate change. Governments, companies, NGOs and individuals can all contribute. Options with high potential for impact are listed below.

Reducing Emissions from the Food System

Strategies for reducing emissions of heat-trapping gases from the food system are often divided into two broad categories: supply side and demand side. Supply-side strategies focus on land use, agricultural production and food distribution. Demand-side strategies focus on food consumption and consumer choice.¹⁰⁷





Supply-Side Strategies

Goals	Strategies
Sustainable Land Use 	<ul style="list-style-type: none"> • Improve agricultural productivity. • Avoid conversion of peatland, wetland, grassland and forest to agricultural use. • Sequester more carbon in soils. • Increase acreage in conservation.
Lower On-Farm Emissions 	<ul style="list-style-type: none"> • Reduce methane emissions from livestock production. • Improve management of chemical fertilizer and manure. • Use fuel-efficient farm vehicles. • Improve irrigation efficiency. • Expand use of renewable energy. • Invest in research and development of climate-smart production technology.
Efficient Distribution Systems 	<ul style="list-style-type: none"> • Increase energy efficiency across the supply chain. • Expand renewable energy use across the supply chain. • Use climate-friendly refrigerants (no CFCs or HFCs). • Shorten food supply chains. • Reduce food loss in distribution.

Measurement and monitoring of the emissions impact of many of these strategies can be challenging. In addition, system effects must be considered before pursuing one of these strategies with the goal of reducing emissions. (Shorter food delivery supply chains can be counterproductive, for example, if food is grown in energy intensive greenhouses powered by fossil fuels.)



The potential for quick and cost-effective emissions reductions in this area is significant. The IPCC found with high confidence that roughly 3%–8% of global emissions of heat-trapping gases could be cut by 2030 with crop and livestock measures at costs in the range of \$20–\$100 t CO₂-eq.¹⁰⁸

Demand-Side Strategies

Goals	Strategies
Less Food Waste 	<ul style="list-style-type: none"> • Reform date labels to minimize premature discarding of useable food. • Conduct public education campaigns about food waste. • Cut oversize portions in restaurants.
Healthy and Sustainable Diets 	<ul style="list-style-type: none"> • Promote plant-rich diets with nutritional guidelines and public education campaigns. • Reduce beef consumption in developed countries. • Include sustainability criteria in food procurement guidelines for government and other institutional purchasers.
More Efficient Cooking Technology 	<ul style="list-style-type: none"> • Expand access to clean cookstoves in developing countries. • Electrify kitchens and use high-efficiency cooktops in advanced economies.
Zero Emissions Waste Disposal 	<ul style="list-style-type: none"> • Expand composting. • Capture methane emissions from solid food waste in landfills. • Burn methane from food waste for energy generation, coupled with carbon capture and storage.

Improving Resilience of the Food System

The food system often relies on long supply chains that are vulnerable to climate disruption at many points. Policies to improve the climate resilience of the food system focus on ensuring a stable food supply and sustainable farmer livelihoods, as well as improving food availability and access.

Goals	Strategies
Stability of Food Supply 	<ul style="list-style-type: none"> • Research and develop drought- and flood-resistant crop varieties. • Adopt climate-resilient cropping systems. • Promote efficient irrigation, sustainable groundwater management and soil health practices to manage increasing water stress. • Expand insurance programs to better manage risk exposure to extreme climate events. • Protect biodiversity in and around agricultural production areas.
Food Availability and Access 	<ul style="list-style-type: none"> • Invest in robust, decentralized storage and cold chain systems. • Improve distribution infrastructure and markets so food surpluses can be effectively dispersed in times of need, including disaster relief. • Increase supply chain efficiency to minimize food loss. • Shorten supply chains where possible. • Improve supply chain energy efficiency to reduce the impact of energy price volatility on food prices.

Policy Tools

Many policy tools are available to implement strategies such as the above. The choice of policy tools will vary from jurisdiction to jurisdiction, depending on local circumstances. Such tools include public funds for research and development, tax incentives, direct payments, regulatory standards, and education through agricultural extension services. Policies that focus on energy use more broadly (such as fuel efficiency standards for vehicles or energy efficiency standards for refrigerators) will also reduce food system emissions.¹⁰⁹

Policies that help reduce emissions from the food system or improve food system resilience can have important benefits in other areas. These include the following:

- improving public health,
- enhancing rural livelihoods,
- empowering women and indigenous peoples,
- promoting animal welfare, and
- protecting biodiversity.¹¹⁰

Conclusion

The world's population is projected to increase from roughly 7.8 billion today to nearly 10 billion people by 2050.¹¹¹ As this happens, development successes will increase per capita calorie consumption and change dietary preferences.¹¹² Innovation and efficiency gains will improve agricultural productivity.¹¹³ Urbanization will result in more people living further from food production.¹¹⁴ These and other trends will shape the food system in the decades ahead.

Transforming the food system to reduce its enormous climate change footprint and ensure its resilience in the face of increasing weather extremes will be a significant challenge. Achieving that goal would help create a food system that delivers human health, shared prosperity and a livable planet. This transformation will involve policy makers, the business community and every one of us.

By **David Sandalow, Cynthia Rosenzweig, Matthew Hayek, Philippe Benoit, Francesco Tubiello, Kevin Karl and Erik Mencos Contreras**

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Food Climate Partnership

The Food Climate Partnership is a joint effort of scholars at the Center on Global Energy Policy at Columbia University, the Agricultural Model Intercomparison and Improvement Project (AgMIP), and New York University. The Food Climate Partnership works to address knowledge gaps, promote better policies and improve public understanding of issues related to the food system and climate change. We work closely with experts at the Statistics Division of the Food and Agriculture Organization (FAO) of the United Nations to ensure that data on food systems are properly analyzed and communicated.



Notes

1. Measured in CO₂-equivalents. Francesco N. Tubiello et al., “Greenhouse Gas Emissions from Food Systems: Building the Evidence Base,” *Environmental Research Letters* 16, no. 6 (2021), <https://iopscience.iop.org/article/10.1088/1748-9326/ac018e>. See also Cynthia Rosenzweig et al., “Climate Change Responses Benefit from a Global Food System Approach,” *Nature Food* 1, no. 2 (2020), 94–97, <https://doi.org/10.1038/s43016-020-0031-z>.
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6. Cynthia Rosenzweig et al., “Finding and Fixing Food System Emissions: The Double Helix of Science and Policy,” *Environmental Research Letters* 16, no. 6 (2021), <https://iopscience.iop.org/article/10.1088/1748-9326/ac0134>.
7. Food products that never enter into commerce, such as crops consumed by those who grow them, are not included in this estimate. Martein Van Nieuwkoop, “Do the Costs of the Global Food System Outweigh Its Monetary Value?” World Bank Blogs, June 17, 2019, <https://blogs.worldbank.org/voices/do-costs-global-food-system-outweigh-its-monetary-value>.
8. Mbow et al., “Food Security.”
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11. FAOSTAT, “Land Cover,” FAO, last modified September 10, 2020, <http://www.fao.org/faostat/en/#data/LC>. See also Hannah Ritchie, “Half of the World’s Habitable Land Is Used for Agriculture,” Our World in Data, November 11, 2019, <https://ourworldindata.org/global-land-for-agriculture>.
12. FAOSTAT, “Land Use Indicators,” FAO, last modified September 10, 2020, <http://www.fao.org/faostat/en/#data/EL>.



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