

THE IMPACT OF CLIMATE CHANGE ON PREPRODUCTION AND POSTPRODUCTION ACTIVITIES OF FOOD SYSTEMS AND VICE VERSA

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Submitted October 24, 2024; Revised December 13, 2024; Accepted December 13, 2024; Published January 20, 2025

ABSTRACT

It is anticipated that the effects of global climate change on food systems will be extensive and intricate, differing throughout time and space and greatly impacted by socioeconomic variables. Climate change would affect agricultural yields and profits, food costs, the dependability of food supply, food quality, and most importantly, food safety, according to historical statistical research and integrated assessment models. Due to their limited ability to invest in institutions and adaptive technology in the face of growing climate hazards, low-income food producers and consumers will be especially vulnerable to climate change. Food security, adaptation, and mitigation may work in concert, but promising strategies like waste reduction and agricultural intensification will need careful management to balance costs and benefits.

Keywords: Food system, food supply, climate change, impact, review

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INTRODUCTION

In the second half of the twentieth century, the global food supply and distribution advanced rapidly enough to keep pace with population growth, leading to improved food security in many regions by providing more affordable, reliable, and safe food for all societal sectors. However, the last decade has witnessed a significant reversal of these gains. Today, achieving food security amid rising food demand, competition for dwindling resources, and the environment's diminishing capacity to cope with increasing human impact is widely regarded as one of the greatest challenges of our time [1]. Among the many

interrelated trends and hazards affecting agriculture and food systems, climate change is a crucial component. Rapid biodiversity loss, changes in land cover, freshwater availability, ocean acidification, and disturbances in the nitrogen and phosphorus cycles are other significant aspects of global environmental change that have an impact on food security. Managing the intricate relationships between socioeconomic and environmental changes will ultimately determine the future of food security [2-4]. One of the biggest risks to food security is climate change, specifically increased variability. This is particularly

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true for low-income people and communities that depend largely on climate-sensitive industries like agriculture and have little ability to adapt. The goal of this study is to present a critical summary of the substantial body of research on the interconnectedness of food systems and climate change. It discusses the opportunities and difficulties for integrating mitigation, adaptation, and food security measures within food systems, emphasizes broader issues beyond food production, and shows how climate-related consequences on food security are distributed throughout global society [5-8].

RELATIONSHIPS BETWEEN CLIMATE CHANGE AND FOOD SYSTEM

A comprehensive analysis of the causes and trends of both observed and anticipated climate change has been conducted. While both are caused by the same radiative forcing, it is helpful to distinguish between short-term increases in climatic variability and long-term (decadal) trends. Without all-encompassing mitigating measures, civilization will eventually have to adjust to slow shifts in the long-term averages and distributions of temperature and precipitation. Either incremental or radical adaptation may be required, depending on the direction and speed of these developments [9].

Currently, climate change is manifesting as increased temporal and spatial variability in temperature, precipitation, and wind patterns, particularly in the frequency and severity of extreme events. Likely increases include the frequency and intensity of heat waves, heavy precipitation events leading to floods, the intensity of tropical cyclones, and the incidence of extremely high sea levels due to storm surges. Additionally, longer dry spells and the areas affected by drought are expected to rise, while the frequency and intensity of cold spells and frosts are likely to decline.

In the short term, the increasing variability of climate has a more immediate impact than longer-term changes in average values, emphasizing the need for a focus on climate risk management in adaptation strategies. This focus will remain crucial, even as the importance of addressing long-term changes in average values grows [10].

The production and distribution of inputs (such as seeds, animal feed, fertilizers, and pesticides), agricultural production (crops, livestock, fisheries, and wild foods), primary and secondary processing, packaging, storage, transportation, distribution, marketing, retail, and catering, as well as domestic food management and waste disposal, are all included in food systems. These supply chains are sometimes linked by a "cold chain," which prolongs the shelf life of both processed and fresh foods by using constant refrigeration. Crucially, food systems encompass not just these actions but also their results and management. Everybody is involved in food systems, pursuing a variety of goals include making a living, making money, protecting the environment, and obtaining food for social, recreational, and nutritional purposes [11].

Food systems around the world are undergoing significant changes due to various demand-side factors, including population growth, shifting consumption patterns, urbanization, and income distribution. Additionally, supply-side trends are influenced by climate change, competition for resources such as water, energy, and land, and the interplay between food production and other ecosystem services. Other notable trends include evolving institutional and social dynamics within the food system, such as trade liberalization, the increasing market presence of transnational food companies, the shift toward supermarket retailing, food industry marketing strategies, and changing consumer attitudes regarding social status,

health, and sustainability.

Overall, there isn't a singular global food system; rather, there are interconnected supply chains for specific products that can vary in scale, from global commodities like soy protein to more localized staples like cassava in many regions [12].

Compared to other resource-based businesses like mining and minerals, the food industry is particularly competitive and fragmented. Less than 20% of retail sales by value are accounted for by the top 50 food processors, which means that their proportion of the overall food consumption across all formal, informal, and non-market channels is significantly lower. Certain food categories, such as coffee, and parts of the supply chain, especially the retail and seed supply industries, are extremely concentrated, though.

IMPACTS OF FOOD SYSTEMS ON CLIMATE CHANGE

Food system activities significantly contribute to the production of greenhouse gases and other climate change drivers, such as aerosols and changes in albedo. However, some agricultural practices, particularly certain agroforestry systems, can sequester carbon, especially when used to restore degraded land. greenhouse gases emissions vary considerably across different food chain activities globally, with notable differences among countries [13].

When aggregating data across the global food chain and assuming an annual emissions growth of 3%, total global greenhouse gases emissions from the food system in 2008 are estimated to range from 9,800 to 16,900 megatonnes of carbon dioxide equivalent, which includes indirect emissions related to land-cover change. This means the food system accounts for 19%–29% of total global anthropogenic greenhouse gases emissions. Agricultural production alone contributes 80%–86% of these emissions globally, though this varies by country. The remaining

emissions stem from preproduction activities (mainly fertilizer manufacturing) and postproduction processes, which include processing, packaging, refrigeration, transportation, retail, catering, domestic food management, and waste disposal (landfills).

It's important to note that these figures rely on extrapolation from single-country data. This discrepancy may suggest a future trend in global food system emissions, with an increasing share linked to postproduction stages of the food chain.

PREPRODUCTION ACTIVITIES

Animal Feed

The production of feed for livestock and aquaculture directly contributes to greenhouse gas emissions through fossil fuel inputs associated with cultivation, transport, and processing. Additionally, it indirectly contributes through land-use changes for both grazing and feed cultivation. Although research on this topic is limited, estimates indicate that more than half of the total energy consumed in livestock production is devoted to feed production. Approximately 20% of the 80 million tonnes of nitrogen fertilizer produced annually is used for cultivating livestock feed. The best estimates for 2005 indicate that whereas overall on-farm fossil fuel use for feed production generated about 60 MtCO₂e, fertilizer use in worldwide feed cultivation resulted in 41 MtCO₂e emissions, taking into account large regional differences [14–17]. In addition to the production of fertilizer, energy is also used in the manufacturing of seeds, pesticides, herbicides, fuel for machinery, electricity for irrigation, heating, drying, and processing. Compared to monogastric animals, ruminants need more feed per kilogram of meat, which results in higher emissions per kilogram of product. On the other hand, ruminant production in large-scale grazing systems on unsuitable ground for crop cultivation can reduce emissions brought on by changes in land use.

Fertilizers

Much of food production relies on various inputs, including tillage, seeds, fertilizers, irrigation, pest and disease control, and animal feed. Among these, fertilizer production is the largest source of greenhouse gas emissions, primarily due to its energy intensity and the release of nitrous oxide during the manufacturing of nitrate fertilizers. In 2007, fertilizer production emitted between 280-570 million tonnes of CO₂ equivalent. The nitrous oxide emissions associated with fertilizer application, which other studies attribute to the agricultural production stage [18].

Natural gas is the fuel for 67% of the world's ammonia production because of its reduced greenhouse gas emissions per energy output. Ammonia is a crucial component in the synthesis of fertilizer. Nonetheless, coal is still used in 27% of ammonia production, mostly in China. There is little information on greenhouse gas emissions from the production and application of agricultural pesticides. According to a recent global estimate, crop protection emissions can range considerably from 3-140 million tonnes of CO₂ equivalent annually.

PRODUCTION ACTIVITIES

Agricultural production significantly contributes to greenhouse gas emissions, both directly through farming practices and indirectly through land-use changes associated with expanding agricultural land. Despite numerous reviews, particularly those by the Intergovernmental Panel on Climate Change, considerable uncertainty remains regarding many of the estimates related to agriculture's impact on climate change.

Direct Emissions

In 2005, direct emissions from agricultural production accounted for approximately 60% of global nitrous oxide (N₂O) emissions and about 50% of methane (CH₄) emissions [19]. The net carbon dioxide (CO₂) flux from agriculture is relatively small, with

agricultural soils serving as both sinks and sources. It was estimated that total direct emissions from agriculture represented 14% of global anthropogenic emissions in 2004. This figure was later refined to estimate direct emissions at 10-12% of total global anthropogenic emissions, translating to approximately 5000-6000 MtCO₂e based on 2005 levels. The primary sources of these direct emissions include N₂O emissions from soils (38%), methane from enteric fermentation (32%), biomass burning (12%), rice production (11%), and manure management (7%).

Indirect emissions

In 2005, agriculture occupied 37% of the Earth's terrestrial surface. Approximately 80% of the new land used for crops and pastures comes from converting forests, particularly in tropical regions. Land-use change is a significant source of CO₂ emissions, contributing an estimated 17% of global greenhouse gas emissions according to the Intergovernmental Panel on Climate Change. This estimate was later revised downward to 12% (with a range of 6% to 18%) of total anthropogenic emissions in 2008, accounting for deforestation, forest degradation, and peatland degradation. Emissions from peatland degradation are substantial, amounting to about a quarter of those from deforestation and degradation [20].

A quantitative study using compiled data from various sources estimated that agriculture is responsible for three-quarters of global deforestation and degradation, with just over half attributed to smallholder agriculture. The remainder is linked to ranching and commercial crops. Recent meta-analyses indicate that while small farmers were significant agents of change, agribusiness has become increasingly influential, particularly in the extensive forested areas of Brazil and Indonesia. In much of Africa and South Asia, smallholders still drive considerable land-use

change; however, ongoing globalization and urbanization are likely to elevate agribusiness as the primary driver.

Agricultural Emissions and Regional Variation

By combining known direct and indirect emissions and assuming that three-quarters of deforestation, forest degradation, and peatland degradation is due to agriculture, agricultural production contributes between 15-25% of total global anthropogenic emissions. Evidence suggests that the scale of direct and indirect emissions varies by region. In sub-Saharan Africa, agricultural emissions total about 1500 MtCO₂e per year, with nearly half originating from indirect emissions. In South and Southeast Asia, total agricultural emissions reach approximately 3000 MtCO₂e per year, similarly split with about half or slightly more coming from indirect emissions. In other regions, carbon sequestration from forest growth and expansion surpasses emissions from agriculturally driven deforestation. In the United States and Canada, total agricultural emissions are just under 500 MtCO₂e per year.

In North America and China, land-cover change does not have an indirect impact; however, the food systems in these countries are linked to land-cover changes in other regions through imports. The significance of various sources of direct emissions differs across regions. For instance, in South and Southeast Asia, direct emissions primarily stem from rice cultivation, N₂O emissions from soils, and enteric fermentation. In contrast, sub-Saharan Africa sees a substantial portion of its emissions come from biomass burning.

POSTPRODUCTION ACTIVITIES

Food Processing

Greenhouse gas emissions from food processing include CO₂ from combustion in cookers, boilers, and furnaces, as well as CH₄ and N₂O from wastewater systems. In 2007, food processing accounted for 48 MtCO₂e of

emissions in China. The processing of sugar, palm oil, starch, and corn is the main contributor to global food processing-related greenhouse gas emissions. Among these, corn wet milling is the most energy-intensive process, consuming 15% of the total energy used by the US food industry. Most primary processing activities have relatively low energy intensities: edible oils require about 11 GJ per tonne, sugar requires 5 GJ per tonne, and canning operations need 10 GJ per tonne. Secondary processing activities vary more significantly; for example, bread making requires between 2 and 5 GJ per tonne, while the manufacture of breakfast cereals requires between 19 and 66 GJ per tonne.

Food Packaging

Information on greenhouse gas emissions from food packaging is limited and challenging to interpret, as it often encompasses the manufacturing of packaging materials, the packaging process itself, and a portion of the refrigeration costs related to the cold chain. It has been noted that packaging plays a minor role in the overall greenhouse gas emissions from food for both vegetables and meat, accounting for approximately 7% of food-related greenhouse gas emissions in the UK [22].

Transportation

Food transportation is a major source of greenhouse gas emissions, and the term "food miles" is frequently addressed in both popular and scientific media. In the UK, food transportation accounted for 19 MtCO₂e in 2002, of which 10 Mt were emitted domestically, mostly from road transit. According to Brodt, 5 kg of food may be transported just 1 km by vehicle, 43 km by air, 740 km by truck, 2400 km by rail, and 3800 km by ship using the same amount of fuel.

Refrigeration

The most energy-intensive part of the food supply chain is found to be refrigeration, not transportation or food miles. The cold chain is thought to be responsible for roughly 1% of all

global greenhouse gas emissions, or 490 MtCO₂e at 2004 levels, according to a small amount of data that has been combined; the ratio is much higher in high-income nations [23].

In the UK, around 2.4% of greenhouse gas emissions are attributed to food refrigeration, and this figure could rise to 3–3.5% when considering "embedded" refrigeration in imported foods. GHG emissions from refrigeration arise from energy use as well as from the production and direct leakage of refrigerants used in cooling systems. It is estimated that 15% of global electricity consumption is dedicated to refrigeration. In 2009, leakage of chlorofluorocarbon refrigerants contributed to 30% of supermarkets' direct greenhouse gas emissions in the UK. While major retailers in Europe are transitioning to non- chlorofluorocarbon refrigerants, chlorofluorocarbon may still significantly impact greenhouse gas emissions in other countries. Furthermore, it is anticipated that the demand for refrigeration will increase with rising ambient temperatures, consequently elevating associated greenhouse gas emissions.

Food waste

Food waste contributes to greenhouse gas emissions primarily through methane emissions from landfills. Emission rates from landfills vary significantly based on the waste composition and management practices. In the United Kingdom, the food portion of landfills is estimated to emit between 2-13 million metric tons of CO₂ equivalent (MtCO₂e) per year in CH₄. However, the more significant impact of waste on greenhouse gas emissions comes from its indirect effects, particularly the embedded emissions associated with the production, distribution, and refrigeration of wasted food. In 2011, avoidable food waste in the UK was responsible for an estimated 20 MtCO₂e of emissions. Food waste in the US rose from 30% of the country's total

food supply in 1974 to 40% in 2003. Avoidable food waste in the US post-production food chain is thought to contribute to greenhouse gas emissions surpassing 113 MtCO₂e annually, making about 2% . Greenhouse gas emissions and 13% of the country's total food-related emissions. Over the past 30 years, there has been little data collecting in medium- and low-income countries, and estimates of waste levels across various nations or food systems frequently rely on questionnaire answers rather than actual measurements [24].

Food Outlets

Energy consumption in modern retail food outlets plays a significant role in greenhouse gas emissions. In the United Kingdom, the total annual emissions from major retail food outlets are estimated to be around 4 million tons of CO₂ equivalent. The energy usage of supermarkets is influenced by various factors, including business practices, store format, product mix, shopping activity, and the equipment utilized for food preparation, preservation, and display. Electrical energy consumption can vary significantly, ranging from approximately 700 kWh per square meter of sales area per year in hypermarkets to over 2000 kWh per square meter in convenience stores. Refrigeration accounts for a substantial portion of electrical energy consumption in retail food stores, comprising about 25-30% in hypermarkets and exceeding 60% in food-oriented convenience stores [25, 26].

Contribution of Food Management

Food preparation contributes to greenhouse gas emissions primarily through energy use related to cooking and refrigeration. Catering is estimated to account for 6% of direct food chain emissions in the UK, while home cooking, storage, and preparation contribute 9%. These statistics are largely unavailable for low- and middle-income countries. Cooking and baking account for over 60% of the energy

used by small businesses in Africa. Additionally, compared to high-income contexts, cooking accounts for a significantly higher portion of overall household energy use in low-income households and nations. The shift to different domestic cooking fuels as household incomes rise is a major contributing element to increased emissions.

CONCLUSION

The post-production stages of the food chain emit greenhouse gas emissions comparable to those from production stages in high-income countries. However, in middle-income and low-income countries, agriculture remains the dominant source of emissions globally. The contributions of direct and indirect emissions from agriculture vary significantly by region. The interplay between climate change and other global environmental, demographic, and economic changes complicates the generation of precise long-term predictions regarding adaptation needs. The entire food chain will be impacted by direct climate change, but agriculture will be most affected because of its climatic sensitivity and crucial role in both the supply of food and the livelihoods of impoverished people. There will be more varied and complex indirect effects on poverty, livelihoods, health, and nutrition.

Despite the uncertainties and potential trade-offs between food security and mitigation goals, various actions can simultaneously enhance food production, adaptation, and mitigation. Many promising options focus on improving resource-use efficiency or managing risks within agriculture and the post-production food supply chain. Many of these strategies are low-cost and based on existing practices, representing good practice even in the absence of climate change; however, barriers such as information gaps and inadequate institutional support hinder broader implementation.

Author(s) Contribution: Analysis, resources data and review, Qurat-ul-Ain.

Funding: No funding involved.

Ethical Approval: Not applicable

Conflict of Interest: Nil.

Consent for Publication: All authors approved the manuscript for publication.

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