

ENVIRONMENTAL RESEARCH
LETTERS

PERSPECTIVE

Finding and fixing food system emissions: the double helix of science and policy




OPEN ACCESS

RECEIVED
30 November 2020REVISED
17 March 2021ACCEPTED FOR PUBLICATION
30 March 2021PUBLISHED
8 June 2021

Original content from this work may be used under the terms of the [Creative Commons Attribution 4.0 licence](#).

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.



Cynthia Rosenzweig^{1,2,*} , Francesco N Tubiello³ , David Sandalow⁴, Philippe Benoit⁴ and Matthew N Hayek⁵ 

¹ Goddard Institute for Space Studies, NASA, New York, NY, United States of America

² Center for Climate Systems Research, Columbia University, New York, NY, United States of America

³ Statistics Division, Food and Agriculture Organization of the United Nations, Rome, Italy

⁴ Center on Global Energy Policy, School of International and Public Affairs, Columbia University, New York, NY, United States of America

⁵ Department of Environmental Studies, New York University, New York, NY, United States of America

* Author to whom any correspondence should be addressed.

E-mail: crr2@columbia.edu

Keywords: food system, greenhouse gas emissions, policy

Improving estimates of greenhouse gas (GHG) emissions from food production, supply, consumption, and disposal is fundamental to identifying effective policy solutions. Through broader awareness of the food-climate nexus, climate mitigation as well as resilience can be enhanced. However, work is needed to address knowledge gaps, promote better policies and improve public understanding of issues related to the food system and climate change. The intention of this paper is not only to highlight the need for better scientific understanding of the processes through which GHGs are emitted—from production to processing, from supply chains and retail to food preparation and waste (figure 1)—but also to integrate science and policy in order to scale up impact on climate change action.

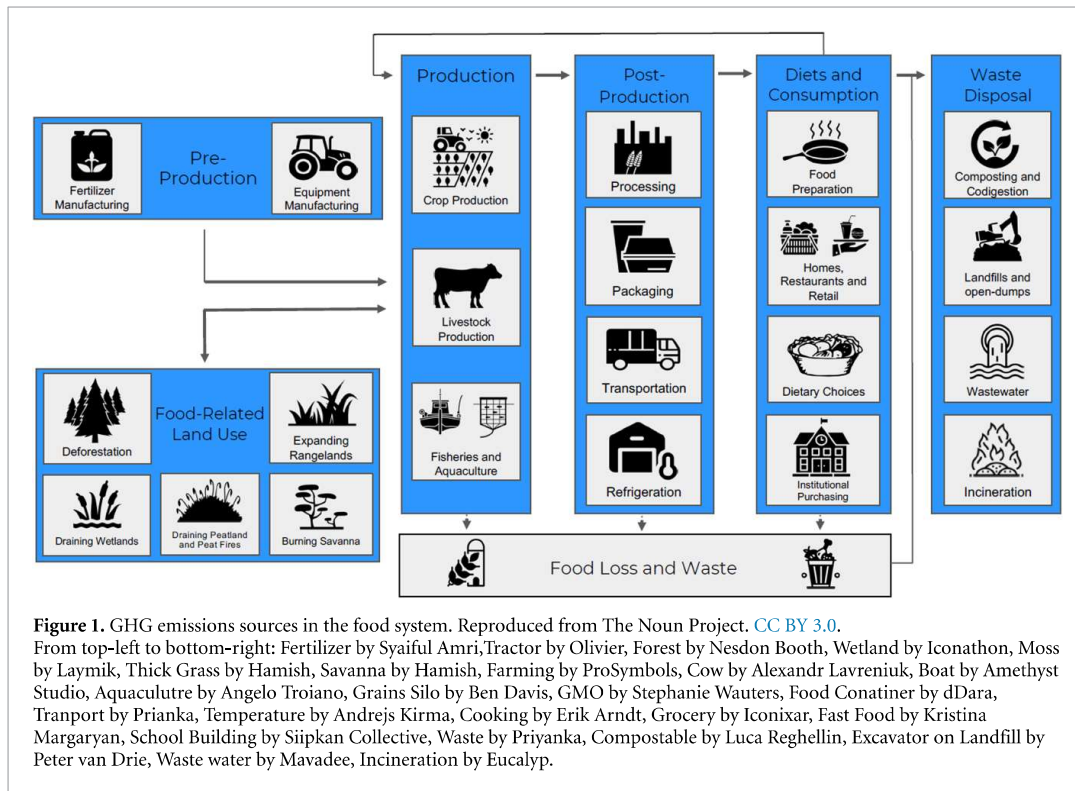
Beyond calculating the emissions from fertilizer decomposition in the soil (e.g. Muhammad *et al* 2011), from converting forests to pastures (e.g. Han and Zhu 2020), from diesel combustion in tractors and fishing boats (e.g. Tomić *et al* 2013, Ziegler *et al* 2013), and from cows and other ruminants (e.g. Herrero *et al* 2013), we need to cast a broader yet tighter net (see, e.g. Crippa *et al* 2021) to better identify the myriad ways in which the food system generates emissions. For example, much of the work to address the impact of the food system on climate change globally has focused on crops and livestock, with less attention paid to aquaculture and fisheries and associated value chains.

In addition, a significant portion of total global energy consumption is for food (FAO 2011). Energy use occurs throughout the food system, including in fertilizer manufacturing, food packaging and food

preparation for consumption (i.e. cooking itself). Socioeconomic systems, political systems, and human dynamics are also crucial, including demographics, economics, behavior, culture, policy, and institutions. Further, this broader food system perspective can provide a useful framework for developing solutions aimed at achieving the Sustainable Development Goals (Pradhan *et al* 2017).

Food-related GHG emissions are traditionally reported by Parties to the United Nations Framework Convention on Climate Change based on the Intergovernmental Panel on Climate Change (IPCC) guidelines (Calvo Buendia *et al* 2019). These guidelines embed food system emissions in multiple inventory categories, such as agriculture, transport, industry, waste, and energy, irrespective of fundamental connections between food supply and demand dynamics (Poore and Nemecek 2018). However, climate change mitigation and adaptation strategies associated with the food system are likely to be inefficient and possibly counterproductive unless food-related emissions from these various sectors are conceptualized as a unified whole (Rosenzweig *et al* 2020). Complementing the supply analysis with the demand side of the food system, for instance through changes in dietary choices, can lead to overall GHG emission reductions (Mbow *et al* 2019).

Science and policy domains have often been siloed in academia. We suggest that a ‘double helix’ of interactive research by scientists and policy experts can deliver significant benefits when analyzing potential food system solutions to climate change. Such deliberate interactions can help to accelerate the



transformation needed to reduce the significant share of GHG emissions arising from the food system. The combined technical and policy solutions to these emissions reductions involve all of the nearly eight billion people on the planet.

The IPCC in its Special Report on Climate Change and Land (SRCL) suggested that the food system is responsible for between 21% and 37% of total GHG emissions caused by human activities (Mbow *et al* 2019, Rosenzweig *et al* 2020). As this estimate highlights, the food system is a major culprit in causing climate change; however, there is large uncertainty in the estimates. Researchers face several challenges. The first challenge is to clearly define the boundaries of the food system and the assumptions that are made in calculating the associated emissions. The related second challenge is to better ascertain the size of food system emissions from the extents of the defined components and processes. In aggregate, this improved characterization could potentially fall outside the range of the recent IPCC SRCL estimates (see e.g. Tubiello *et al* 2021, this Special Issue). A third challenge is to reduce uncertainties so that mitigation policy efforts can be better directed and their effectiveness increased.

There are challenges in the double-helix science and policy approach, such as translating conflicting scientific results into policy recommendations. For example, bottom-up estimates of carbon emissions from agriculture differ substantially from top-down

biogeochemical measurements (Desjardins *et al* 2018). These differences may make policy recommendations difficult to develop and communicate. Moreover, the scope of scientific inquiry should not be constrained by the limitations of what might be practicable from a policy perspective.

There are important opportunities for progress in the short-, as well as medium-term. On the technical side, there is the hard slog of identifying food-related emissions in the big buckets of other relevant economic sectors, such as energy, transport and manufacturing, or important related processes, such as food loss and waste. On the policy side, most countries have yet to include policies for reducing food waste as a mitigation measure in their Nationally Determined Contributions (NDCs) under the Paris Agreement.

The goal should be to improve the measurement, monitoring and reporting of GHGs related to the food system and help countries include food system measures in their climate policies. By complementing supply-side mitigation (e.g. reduced deforestation and ecosystem degradation) with demand-side measures (e.g. change towards climate-friendly diets), countries can cut food system GHG emissions, reduce competition for land, and maintain food affordability. A few—but only a few—NDCs address this. For example, Chile's 2020 NDC highlights the opportunities that the wider food system approach provides:

The agriculture sector offers different options to reduce the magnitude of emissions and increase carbon absorption. These options improve productivity in crops, soil nutrient status, organic waste management, microclimate or biodiversity and, therefore, support climate change adaptation. [However] interventions to demand, modifications in food selection, loss reduction and food waste were not considered in the sector. These options also reduce GHG emissions and improve the resilience of food systems. These measures, together with the mitigation measures in the supply side, allow the implementation of large-scale adaptation and mitigation strategies without threatening food security due to the increased competition for land for food production, and higher prices. (Government of Chile 2020)

The food system generates a significant amount of GHG emissions, many of which are unmeasured or imprecisely measured, across a wide range of interrelated activities, traditionally allocated to sectors other than food and agriculture. These activities include transport of inputs from factories to farms, energy generation for irrigation pumps and cold storage, production of plastics for packaging (including upstream methane leaks involved in producing hydrocarbon feedstock), and power for grocery stores and restaurants. They include the use of fossil fuels by billions of people for food preparation (including those who lack access to clean cooking technologies). The disposal of food waste results in carbon dioxide emissions from transport and methane generation in landfills.

While the food system is central to feeding the world's population and supports the livelihoods of more than one billion people, it falls short in that 690 million people globally are still undernourished (see, e.g. SDG Goal 2). Two billion people are considered overweight or obese, many of whom suffer from chronic and expensive related health conditions (FAO *et al* 2020, Beltran-Peña *et al* 2020, this Special Issue). Actions to reduce food system GHG emissions must not compromise—and ideally should promote—food security, human health, and well-being.

An important food system mitigation option may be reduction of methane emissions from enteric fermentation, especially in cattle. This has been linked with a potential role for dietary change (Willett *et al* 2019). Reduction in meat consumption, especially beef, can deliver health benefits, reduce GHG emissions from livestock production, and augment the

potential to sequester carbon on land not used for grazing or for growing livestock feed (Hayek *et al* 2021). Another emerging solution attracting a lot of attention is reducing or repurposing the significant volumes of food waste generated throughout the system, for example, by converting food waste to feed for aquaculture.

Research and data are needed to inform discussions on the relative benefits for countries in tackling food system GHG emissions. Should policies encourage dietary change, improved food waste management, or both? If both, how? Technical work closely allied to policy analysis in the double helix can respond effectively and in a timely manner to these types of questions.

Challenges in transforming the food system towards a more sustainable planet and a less threatening climate are further exacerbated by the impacts of climate change itself on agricultural production and supply chains (Mbow *et al* 2019). These include increases in temperature (especially heat-waves) across the globe and changes in precipitation causing droughts and floods. Food systems in lower latitudes, which disproportionately are home to developing countries, are the most vulnerable to the impacts of climate change. Such socioeconomic disparities are crucially important because those with greater resources can better withstand the challenges of increasing climate extremes. Multiple global crop and economic models show that such circumstances in combination with imprecisely-targeted mitigation policies (like a globally uniform carbon tax) can increase the risk of hunger (Hasegawa *et al* 2018). High carbon dioxide levels also have been shown to adversely impact nutrient quality: when carbon dioxide increases, protein, iron, and zinc concentrations in the many harvested crops decline (Beach *et al* 2019). Livestock diseases are also affected by global temperature increases (Bett *et al* 2017).

Great care must therefore be exercised in the design of climate-food interventions, and innovative solutions are needed that can deliver adaptation as well as mitigation benefits. The wide spectrum of the way food is produced, delivered, and consumed demonstrates that policy solutions need to be targeted toward specific actors, for instance, agribusiness, which is characterized by corporate consolidation and vertical integration, or the large numbers of smallholder farmers. These enterprises range from farms of less than 1 hectare to vast holdings connected globally.

What policies would have the most short-term impact in reducing GHG emissions from the food system? What policies could have an impact in the medium- and long-term? What policy interventions can cut emissions while improving human health, rural livelihoods, biodiversity protection, and animal welfare? How do social systems interact with food

systems? Where would public investment be most effective? How can markets help? These are urgent policy questions for which countries need answers now.

At the same time however, food-climate policies that reflect changing demographics and incomes are likely to be more effective than those that respond only to present-day needs, as the world's population grows, incomes rise, and the climate changes. (Notably, emerging economies and other developing countries are seeing related changes in food demand and dietary preferences.) These demographic, income, and dietary trends will have an important impact as the food system responds to the challenge of feeding over nine billion consumers by 2050 (United Nations 2019) while simultaneously addressing its prominent role in climate change.

Programs or policies to mitigate climate change must consider the impact on the more than 500 million smallholder households around the world that depend on plots of less than 2 hectares and common grazing land for their food and livelihood. This is a particularly acute issue in the least-developed countries, where relatively larger shares of the population rely on agriculture for their survival. A major challenge is to develop mechanisms for just transitions to sustainable agroecological systems, which may include livestock, in ways that are more resilient and responsive to climate change challenges. Strategies to achieve this goal include better grazing practices, improved land management, diversification of production, improved manure handling, and better-quality feed.

Finally, we note that COVID-19 has highlighted the cascading impacts of global systemic risks on the food system. The pandemic has affected food production through disruption of farm labor, food consumption through supply chain malfunctions, and food access through loss of income—all effects on a food system already stressed by extreme climate events. At the same time, encroachment of agriculture into natural ecosystems and food production—particularly of livestock—are major risk factors for emergence of new pandemics (UNEP and ILRI 2020). COVID-19 and climate change both disproportionately affect poor and minority populations, threatening food security around the world. As we recover from the current pandemic and prepare for the next one, we highlight the importance of integrating food systems into climate change and public health policies, in order to ensure human health and well-being, as well as the health of the planet.

Data availability statement

No new data were created or analyzed in this study.

Acknowledgments

This paper arose from discussions of the Food Climate Partnership, a joint effort of climate change, agriculture, energy, and policy scholars at the Center on Global Energy Policy and the Center for Climate Systems Research at Columbia University, the Agricultural Model Intercomparison and Improvement Project (AgMIP), New York University, and the Food and Agriculture Organization of the United Nations (FAO). We thank Erik Mencos Contreras, Kevin Karl, and Sally Qiu for research and graphics assistance. The views expressed in this publication are those of the authors and do not necessarily reflect the views or policies of FAO.

ORCID iDs

Cynthia Rosenzweig  <https://orcid.org/0000-0002-8541-2201>

Francesco N Tubiello  <https://orcid.org/0000-0003-4617-4690>

Matthew N Hayek  <https://orcid.org/0000-0001-9792-4362>

References

- Beach R H *et al* 2019 Combining the effects of increased atmospheric carbon dioxide on protein, iron, and zinc availability and projected climate change on global diets: a modelling study *Lancet Planet. Health* **3** e307–17
- Beltran-Peña A, Rosa L and D'Odorico P 2020 Global food self-sufficiency in the 21st century under sustainable intensification of agriculture *Environ. Res. Lett.* **15** 095004
- Bett B, Kiunga P, Gachohi J, Sindato C, Mbotha D, Robinson T, Lindahl J and Grace D 2017 Effects of climate change on the occurrence and distribution of livestock diseases *Prev. Vet. Med.* **137** 119–29
- Calvo Buendia E *et al* 2019 *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* pp 1–15 (available at: www.ipcc.ch/site/assets/uploads/2019/06/19R_V0_01_Overview_advance.pdf)
- Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello F N and Leip A 2021 Food systems are responsible for a third of global anthropogenic GHG emissions *Nat. Food* **2** 198–209
- Desjardins R L, Worth D E, Pattey E, VanderZaag A, Srinivasan R, Mauder M, Worthy D, Sweeney C and Metzger S 2018 The challenge of reconciling bottom-up agricultural methane emissions inventories with top-down measurements *Agric. For. Meteorol.* **248** 48–59
- FAO, IFAD, UNICEF, WFP, and WHO 2020 *The State of Food Security and Nutrition in the World 2020* (FAO, IFAD, UNICEF, WFP and WHO) (available at: www.fao.org/documents/card/en/c/ca9692en)
- FAO 2011 *Energy-smart Food for People and Climate. Issue Paper* (Rome, Italy) pp 1–78 (available at: www.fao.org/3/i2454e/i2454e.pdf)
- Government of Chile 2020 *Chile's Nationally Determined Contribution—Update 2020* (available at: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Chile%20First/Chile%27s_NDC_2020_english.pdf)