Climate change responses benefit from a global food system approach

A food system framework breaks down entrenched sectoral categories and existing adaptation and mitigation silos, presenting novel ways of assessing and enabling integrated climate change solutions from production to consumption.

Cynthia Rosenzweig, Cheikh Mbow, Luis G. Barioni, Tim G. Benton, Mario Herrero, Murukesan Krishnapillai, Emma Liwenga, Prajal Pradhan, Marta G. Rivera-Ferre, Tek Sapkota, Francesco N. Tubiello, Yinlong Xu, Erik Mencos Contreras and Joana Portugal Pereira

Food systems[1] have not been cast effectively in either the Intergovernmental Panel on Climate Change (IPCC) or the United Nations Framework Convention on Climate Change (UNFCCC) greenhouse gas (GHG) emissions inventory guidelines[2,3]. Food-related emissions from agriculture, transport, industry and household consumption have traditionally been reported separately, irrespective of fundamental connections between food demand and farm-level production. Unless these are conceptualized as a unified whole, climate change mitigation and adaptation strategies associated with the food system are likely to be inefficient and possibly counterproductive.

IPCC measurement protocols form the basis of national reporting under the UNFCCC and the Paris Agreement[4], and the planned Global Stock Take due in 2023. Yet, a food system approach could be much more useful for countries designing the next stage of their nationally determined contributions as well as for the international community by improving how climate change and agriculture are addressed in three fundamental ways[5].

First, it would liberate agriculture from the 'agriculture, forestry, and other land use' (AFOLU) category of national greenhouse gas emissions inventories, so that the contribution of the global food system to total anthropogenic GHG emissions can be comprehensively calculated. This provides a much clearer picture of emission sources, thereby allowing for the design of more effective response options and the engagement of an expanded set of actors.

Second, a systemic approach facilitates the design of integrated adaptation and mitigation policies, which bring together supply-side (that is, crop and livestock production, processing, storage and transport) and demand-side (that is, dietary change) measures. Reducing food loss and waste as a response strategy is also best addressed across the entire food system.

Third, it provides the relevant framework to identify, analyse and address synergies and trade-offs among different climate change responses, primarily in relation to the potential competition for land to satisfy projected demand for food versus land to contribute to mitigation of climate change (through bioenergy and carbon sequestration). Relevant assessments involve the combined potential of dietary change, reduction of food loss and waste, and 'land-sparing' strategies that enable simultaneous food production, adaptation and mitigation activities.

Table 1 | Comparison of 2007–2016 mean values and standard deviations of emissions from AFOLU[6] and global food system[5] emissions by component, including food loss and waste

	AFOLU		Food system	
Components	**Emissions ($GtCO_2e\ yr^{-1}$)[a]**	**Percentage of anthropogenic GHG emissions (%)[b]**	**Emissions ($GtCO_2e\ yr^{-1}$)[a]**	**Percentage of anthropogenic GHG emissions (%)[b]**
Agriculture	6.2 ± 1.4[18,19]	9–14	6.2 ± 1.4[18,19]	9–14
FOLU[c]	5.8 ± 2.6[6]	6–16	4.9 ± 2.5[18]	5–14
Pre- to post-production	–	–	2.6–5.2[7,8]	5–10[d]
Total	12.0 ± 2.9	17–29	10.8–19.1	21–37

[a]Mean and 95% confidence interval, using GWP values of the IPCC AR5 with no climate feedback ($GWP\text{-}CH_4 = 28$; $GWP\text{-}N_2O = 265$). [b]Computed using a total emissions value for the period 2007–2016 of 52 $GtCO_2e$ per year[6]. [c]Food-related FOLU for food system columns. [d]Rounded to nearest fifth percentile due to assessed uncertainty in estimates.

Table 2 | Food system supply-side and demand-side technical and economic mitigation potentials[5]

Mitigation potential	**Supply side ($GtCO_2e\ yr^{-1}$)**	**Demand side ($GtCO_2e\ yr^{-1}$)**
Technical	2.3–9.6	0.7–8.0
Economic	1.5–4.0[a]	1.8–3.4[b]

[a]By 2030 at prices ranging from 20–100 USD per tCO_2e. [b]By 2050 at prices ranging from 20–100 USD per tCO_2e.

Food system GHG emissions

The addition of GHG emissions from energy use, supply chains and consumption activities to those emitted within the farm gate provides a much more comprehensive depiction of how food is contributing to climate change (Table 1). The result is an overall contribution of a considerable 21–37% of total anthropogenic emissions, compared to ~23% from agriculture combined with land-use change for food production (deforestation and peatland degradation) and

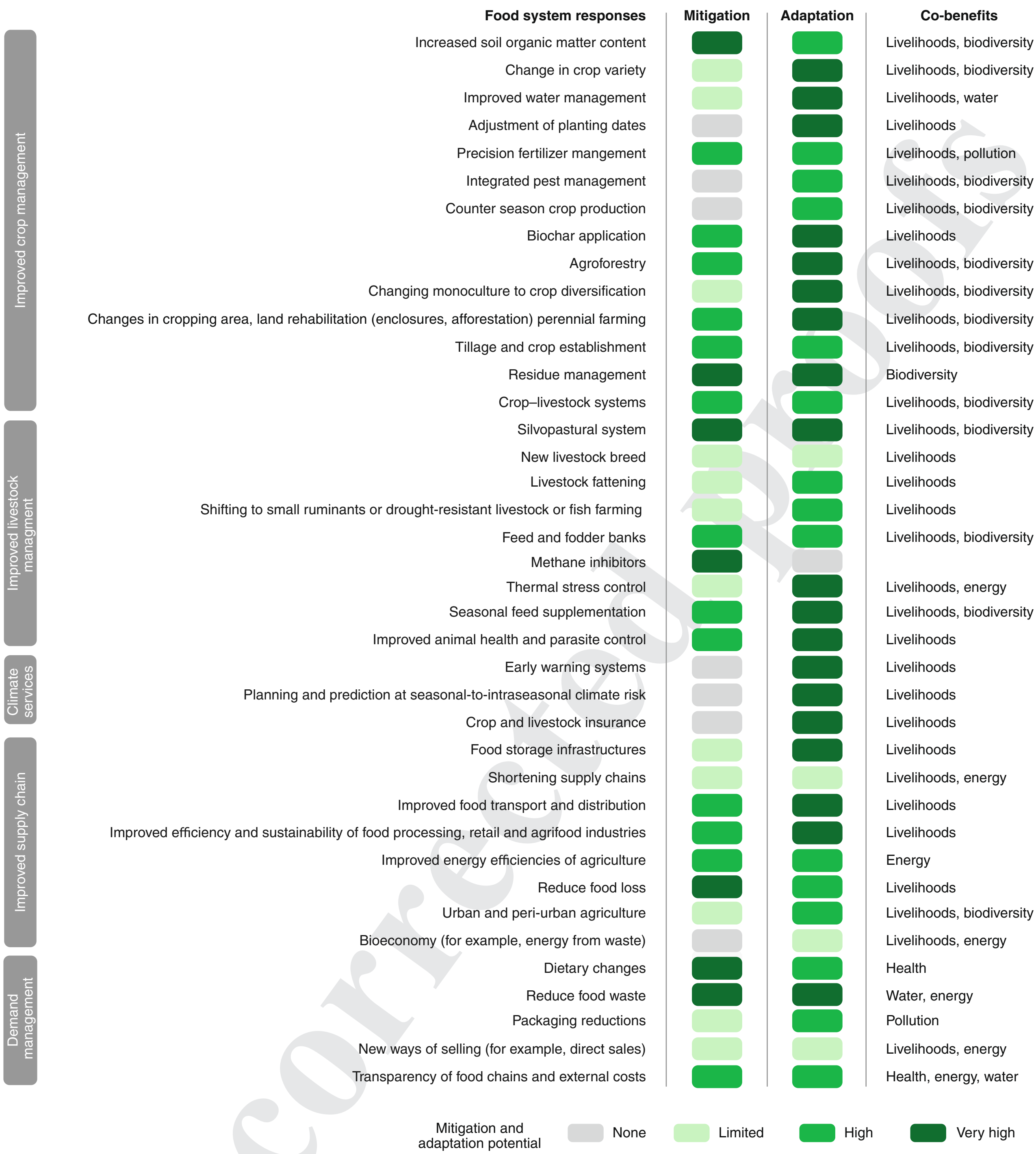

Fig. 1 | Synergies between mitigation, adaptation and other co-benefits resulting from food system climate change response options[5,20]

~10% from agriculture alone when defined as within-farm-gate crop and livestock production (this includes CH_4 from ruminant animals and N_2O from fertilizers)[5,6]. These current assessments, building on earlier syntheses of food systems emissions[7–9], have significantly expanded the global analysis of key sub-components and their contributions to climate change adaptation and mitigation.

Food-related response options

The production, supply, and consumption of food extends far beyond farmers' fields (and producing countries). Hence, the food system approach provides a more appropriate landscape within which policy and response actions can be analysed and implemented. Such a framework favours the link between resilience, adaptation and mitigation at scale, across landscapes and economic activities. This is achieved by complementing the more traditional supply-side responses focused on farm activities with demand-side responses that focus more broadly on consumer and industry behaviour — such as dietary change, reduction of food loss (reduction of edible food during production, postharvest and processing)[10] and reduction of food waste (food discarded by consumers and retailers)[10].

Dietary change. The EAT/Lancet Report raised awareness of the role that dietary choices can play jointly, and thus more effectively, in addressing pressing health and climate change challenges[11,12]. The consumption of healthy and sustainable diets presents major opportunities for enhancing resilience (for example, through diversification), reducing GHG emissions from the food system (for example, from decreasing production of emissions-intensive animal-sourced products) and expanding climate change adaptation options (for example, by promoting sustainable agricultural management that conserves soil and water). Table 2 shows total technical mitigation potentials — the maximum amount of GHG mitigation achievable through technology diffusion — as well as total economic mitigation potentials at specified carbon prices of both crop, livestock and agroforestry activities (supply side) and dietary changes (demand side).

Reduction of food loss and waste. About 8–10% of total anthropogenic GHG emissions correspond to food loss and waste[5], which comprises twenty-five to thirty per cent of global food production[13]. Loss of edible food and food discarded by retailers and consumers create additional demand for agricultural production, thereby increasing GHG emissions and overall pressure on natural resources[14]. Options to reduce food loss and waste can be more easily identified, designed and assessed through a system approach — including technical measures (for example, improved harvesting, on-farm storage, infrastructure, packaging to keep food fresher longer and refrigeration) and behavioural changes (for example, acceptance of less-than-perfect fruit and vegetable appearance, redistribution of food surplus and lowered prices on nearly expired food).

Synergies and trade-offs

Adaptation and mitigation can be jointly achieved across a portfolio of practices, often with added socio-economic co-benefits (Fig. 1). For example, crop management practices such as increasing soil organic matter; erosion control; intercropping; and improved fertilizer, water, and other input management, all increase crop production and its resilience while reducing GHG emissions. Similarly, livestock options such as better grazing land management and improved manure management contribute to both adaptation and mitigation targets.

The identification of potential trade-offs and synergies among climate change responses is crucial to their success. A key trade-off involves competition between land use for bioenergy and carbon sequestration, to contribute to climate change mitigation versus agricultural land use for food production. As analysed by the Agricultural Model Intercomparison and Improvement Project (AgMIP)[15], bioenergy and carbon sequestration projects, especially at large scale, might encourage 'land grabbing' with negative trade-off effects on smallholder livelihoods and their food security[16]. These negative effects require parallel actions at the demand level, which can generate the needed counterbalancing 'land-sparing' effects. These may include, for instance, large-scale education campaigns and implementation of the needed regulatory environments aimed at promoting dietary changes linked to more efficient and sustainable land use for agriculture.

Further, attention needs to be paid to 'rebound effects,' by which gains in GHG emissions efficiencies can be offset by increases in total emissions due to expansion of production linked to the increased efficiencies. Appropriate regulations and incentives, as well as monitoring systems, will need to be put in place to ensure that actual emission reductions in farming systems are taking place[17].

Scaling up climate change responses

The food system approach offers significant advances for the implementation of climate change adaptation and mitigation measures. By explicitly recognizing fundamental connections between consumer demand, dietary choices and production, it favours the integration of a much broader set of actors and institutions. Yet, the scaling up of climate responses requires further research.

First, a complete accounting of food system emissions is needed. The recent *IPCC Special Report on Climate Change and Land* revealed that many GHG sources — such as grain drying, packaging and supply-chain emissions — are less well characterized than those accounted for in AFOLU[5].

The dynamics of dietary change and their linkage to climate and health also need to be better understood. Key topics include the contribution of different measures in promoting a shift towards healthy and sustainable diets, the economic impact of such measures in regard to reduced healthcare costs, how and at what rate dietary change can feedback to changes in agricultural production, and what are their social and environmental impacts.

Finally, it is essential to find actionable ways to increase adoption of key adaptation and mitigation practices, for example, rigorous testing of the role of incentives and rapid development of innovative techniques such as circular economies. Modelling and ex ante simulations of adaptation and mitigation synergies can shed light on what are the potential barriers to implement specific practices, how to avoid competition between climate change mitigation and food security, and which governance structures favour equitable participation in climate change solutions. ❐

Cynthia Rosenzweig[1,2*], Cheikh Mbow[3], Luis G. Barioni[4], Tim G. Benton[5,6], Mario Herrero[7], Murukesan Krishnapillai[8], Emma Liwenga[9], Prajal Pradhan[10], Marta G. Rivera-Ferre[11], Tek Sapkota[12], Francesco N. Tubiello[13], Yinlong Xu[14], Erik Mencos Contreras[1,2] and Joana Portugal Pereira[15,16]

[1]NASA Goddard Institute for Space Studies, New York, NY, USA. [2]Columbia University, Center for Climate Systems Research, New York, NY, USA. [3]Future Africa at the University of Pretoria, Pretoria, South Africa. [4]Embrapa Agricultural Informatics,Laboratory of Agri-Environmental Modelling, Campinas, Brazil. [5]University of Leeds, School of Biology, Leeds, UK. [6]Royal Institute of International Affairs, London, UK. [7]Commonwealth Scientific and Industrial Research Organisation, St Lucia, Queensland, Australia. [8]College of Micronesia-FSM, Yap Campus, Colonia, Yap, Federated States of Micronesia. [9]University of Dar es Salaam, Institute of Resource Assessment, Dar es Salaam, Tanzania. [10]Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany. [11]University of Vic-Central University of Catalonia, Chair Agroecology and Food Systems, Barcelona, Spain. [12]International Maize and Wheat Improvement Center, El Batan, Texcoco, Mexico. [13]FAO, Statistics Division, Viale delle Terme di Caracalla, Rome, Italy. [14]Chinese Academy of Agricultural Sciences, Climate Change Lab, Haidian District, Beijing, China. [15]Universidade Federal do Rio de Janeiro, Graduate School of Engineering, Centro de Tecnologia, Cidade Universitária, Ilha do Fundão, Rio de Janeiro, Brazil. [16]Imperial College London, Centre for Environmental Policy, South Kensington Campus, London, UK.

**e-mail: cynthia.rosenzweig@nasa.gov*

https://doi.org/10.1038/s43016-020-0031-z

References

1. Ingram, J. *Food Secur.* **3**, 417–431 (2011).
2. Calvo Buendia, E. et al. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (2019).
3. *National Inventory Submissions 2019* (UNFCCC, 2019).
4. *The Paris Agreement* (UNFCCC, 2015).
5. Mbow, C. et al. in *Climate Change and Land* (eds. Shukla, P. R., Skea, J., Calvo Buendia, E. & Masson Delmot, V.) Ch. 5 (IPCC, 2019).

6. Jia, G. et al. in *Climate Change and Land* (eds. Bernier, P., Espinoza, J. C. & Semenov, S.) Ch. 2 (IPCC, 2019).
7. Poore, J. & Nemecek, T. *Science* **360**, 987–992 (2018).
8. Fischedick, M. et al. in *Climate Change 2014: Mitigation of Climate Change* (eds. Edenhofer, O. et al.) Ch. 10 (Cambridge Univ. Press, 2014).
9. Vermeulen, S. J., Campbell, B. M. & Ingram, J. S. I. *Annu. Rev. Environ. Resour.* **37**, 195–222 (2012).
10. *Global Food Losses and Food Waste: Extent, Causes and Prevention* (FAO, Rome, 2011).
11. Willett, W. et al. *Lancet* **393**, 447–492 (2019).
12. Dalin, C. & Outhwaite, C. L. *One Earth* **1**, 298–302 (2019).
13. Kummu, M. et al. *Sci. Total Environ.* **438**, 477–489 (2012).
14. Hiç, C., Pradhan, P., Rybski, D. & Kropp, J. P. *Environ. Sci. Technol.* **50**, 4269–4277 (2016).
15. Rosenzweig, C. et al. *Agric. For. Meteorol.* **170**, 166–182 (2013).
16. Hasegawa, T. et al. *Nat. Clim. Chang.* **8**, 699–703 (2018).
17. Paul, C., Techen, A. K., Robinson, J. S. & Helming, K. *J. Cleaner Produc.* **227**, 1054–1067 (2019).
18. Tubiello, F. N. in *Encyclopedia of Food Security and Sustainability* **Vol. 1** (eds. Ferranti, P., Berry, E. M. & Anderson, J. R.) 196–205 (Elsevier, 2019).
19. *Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990–2030* EPA 430-R-12-006 (USEPA, 2012).
20. Smith, P. et al. *Climate Change and Land* (eds. Abdulla, A et al.) Ch. 6 (IPCC, 2019).

Competing interests

The authors declare no competing interests.

QUERY FORM

Nature Food	
Manuscript ID	[Art. Id: 31]
Author	Cynthia Rosenzweig

AUTHOR:

The following queries have arisen during the editing of your manuscript. Please answer by making the requisite corrections directly in the e.proofing tool rather than marking them up on the PDF. This will ensure that your corrections are incorporated accurately and that your paper is published as quickly as possible.

Query No.	*Nature of Query*
Q1:	Please check your article carefully, coordinate with any co-authors and enter all final edits clearly in the eproof, remembering to save frequently. Once corrections are submitted, we cannot routinely make further changes to the article.
Q2:	Note that the eproof should be amended in only one browser window at any one time; otherwise changes will be overwritten.
Q3:	Author surnames have been highlighted. Please check these carefully and adjust if the first name or surname is marked up incorrectly. Note that changes here will affect indexing of your article in public repositories such as PubMed. Also, carefully check the spelling and numbering of all author names and affiliations, and the corresponding email address(es).
Q4:	Please define GWP in the footnotes of Table 1.
Q5:	Please check the chapter numbers and editors added to refs. 5, 6 and 17.
Q6:	As per house style, references have been renumbered in the order: Main text, tables, figures. Please ensure that this has been done correctly.