Putting all foods on the same table: Achieving sustainable food systems requires full accounting

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Improving global food systems is essential to addressing climate change, mitigating biodiversity loss, and meeting both sustainability and human development goals. International assessments from the Intergovernmental Panel on Climate Change and Intergovernmental SciencePolicy Platform on Biodiversity and Ecosystem Services and business and technology innovations such as lab-grown and plant-based meat, as well as many consumer diet trends, can all be traced to studies that identify undesirable impacts of certain food systems.

Yet the evidence underpinning many widely touted recommendations about what to grow and eat is remarkably sparse and generally biased.

We know that not all food is created equal in terms of environmental impact (1–3). However, most past research has focused on only a few key foods (e.g., beef and staple crops) and only a few environmental stressors (particularly greenhouse gas emissions). In addition, these studies tend to be confined to a few countries, and many nations suffer from poor knowledge transfer between the scientific community and the public. Even the most wide-ranging assessments made to date (2, 4, 5) contain significant gaps (Fig. 1). These biases arise, first, because substantial portions of the global food system are inaccurately or insufficiently reported or effectively “hidden” from standard statistics (e.g., inland and small-scale fisheries, bushmeat, backyard farming) and, second, because of an incomplete knowledge of the suite of environmental impacts and how these propagate through the many linkages among food systems.

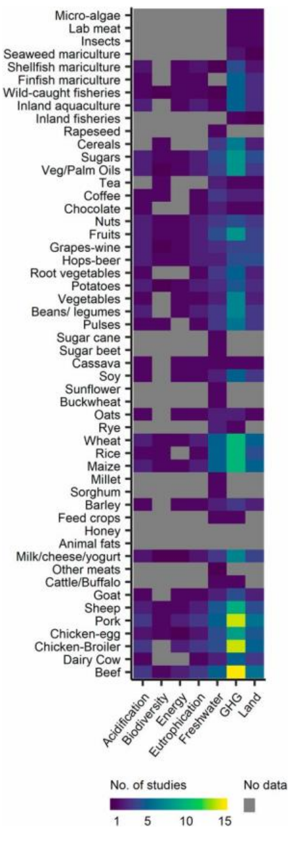

Fig. 1. Comparative food impact studies published in the last 10 years are skewed in favor of a handful of topics. Coverage here was calculated as the number of studies that included each food type and associated stressors and/or impacts. See Table S1 for details. Full data are available in Ext. Data S3. GHG, greenhouse gases.

The web of food impacts and interactions are challenging to map, let alone fully assess. Yet characterizing these linkages is essential to understand the true cumulative impact of food production (2, 3). Without doing so, society risks unknowingly exceeding regional, or even global, environmental boundaries or missing opportunities to steer food consumption and policy toward more sustainable foods and practices. Furthermore, gaps in assessments are unevenly distributed. For example, in developing regions with rapidly growing human populations, unassessed foods underpin the nutrition of millions and provide essential sources of protein for more than three billion people (3, 6, 7). It is hard to imagine developing science-based food policy for regions where so many of the common foods have never been assessed in terms of environmental impacts.

Two major gaps in our understanding—substantial holes in food assessment studies and the nearly complete absence of linkages among foods in these assessments—limit our ability to link environmental impacts to food security. We show how this lack of understanding undermines decision makers' capacity to develop policies ensuring the planet can sustainably meet future human food demands. We recommend tackling these gaps by improving the environmental impact assessment of food production and supporting the development of effective, integrative food policy.

Underassessed Foods and Impacts

Only by putting all foods on the "same table" can we comprehensively evaluate their relative environment impacts, and in turn, develop effective and efficient policies that ensure greater production with lower environmental cost across all foods. "Underassessment" is an acute problem for two reasons. Hidden, missing, and under-reported (hereafter collectively called underassessed) foods represent substantial amounts of food production in many countries around the world. Synthesizing data from open-access databases and published literature, we show that underassessed foods represent more than half of animal production in 76 countries (see Ext. Data 2; Fig. S1) and more than 25% of total food in 40 countries (Fig. 2). For those countries lacking data on their major food groups, it is impossible to generate informed plans for sustainability and food security. In addition, even prominent well-studied foods commonly suffer from very narrow examinations—often only greenhouse gas emissions implications and, perhaps, land and freshwater uses are taken into account (Fig. 1). The omission of marine stressors, such as acidification and plastic pollution, diminishes the value of existing marine food assessments and could expose many regions of the world to tragic environmental breakdowns.

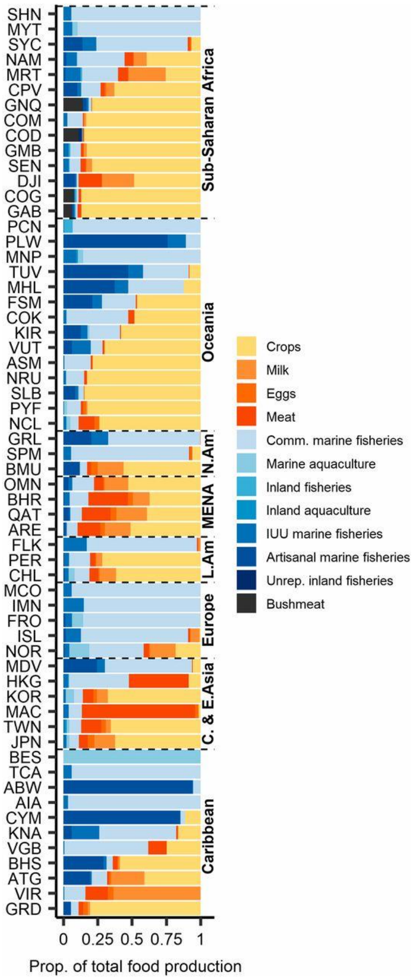

Fig. 2. Among different nations, the proportions of food from crops, livestock, milk, and eggs (warm colors) and various underassessed foods (cool colors) varies widely. Countries are grouped by continent or global region, and only those with greater than 10% underassessed food are shown. The key to the three-letter country codes is provided in Ext. Data S2. Comm., commercial; IUU, illegal, unreported, and unregulated; Prop., proportion; Unrep., unreported

We hypothesize that the environmental impacts of underassessed foods are likely more diverse than conventionally reported commercial agriculture and livestock systems. This variation stems, in part, from the great diversity of species that are farmed and harvested within these underassessed sectors and from the greater range of production and capture methods. Conventionally reported food consists of relatively few livestock species (cows, chickens, pigs, sheep, and goats) and just ten crops (8). In contrast, the wild harvest of aquatic and terrestrial species includes thousands of species, habitats, and capture technologies. These differences will affect the resilience of targeted stocks—and thus the sustainability of the harvest—but also lead to more types of environmental impact and greater variability within each impact (2). For example, although greenhouse gas emissions from marine fisheries are generally lower than estimates from other animal protein production, emissions can vary widely depending on motorization, species, gear type, and location (9).

The additional diversity that these underassessed foods provide—both within and between food types— offers greater opportunities for policymakers to mitigate the environmental impacts of food production. Policy could strategically support the kinds of production most likely to minimize the trade-offs between environmental and other objectives. For example, bushmeat hunting and inland fisheries have potentially serious impacts on native biodiversity and the societal benefits arising from biodiversity. However, these foods are often a vital protein source for marginalized people and have extremely low impacts on water pollution or greenhouse gas emissions compared with other foods. Only by incorporating data on these foods and associated environmental impacts into food system accounting will consumers be able to make fully informed choices and policymakers to identify and evaluate trade-offs within and across food systems. This information is requisite to managing for lower overall food system impacts.

Critical Linkages

Interdependencies among food production sectors are commonplace: manure is used to fertilize crops, land converted to crops is no longer available as pasture, and fish farms displace local wild fisheries. Some linkages are well studied and reveal the complexity of interactions. For example, studies of the ubiquitous linkage between fed animals and their feed have highlighted less-known results that roughly 4% of crops are fed to farmed seafood (8) and 27% of wildcaught fish is used as feed for farmed fish, pigs, and poultry (4).

But few studies have comprehensively accounted for the suite of linkages among systems, despite their significance for the cumulative impact of food production, and more indirect linkages abound. Agricultural pollution limits the location and yield of inland and coastal aquaculture (10), disease and genetic escapes from aquaculture pens can influence the health of wild fish stocks and vice versa (11), and landscape homogenization in the search for more efficient production can disrupt natural pollination and potentially decrease yields (12). Linkages can also generate win-win opportunities. For example, feeding seaweed to cows dramatically reduces methane emissions from cattle while also potentially reducing the need to convert new land to crop cultivation (13). Even more poorly known are the potential linkages among different types of underassessed foods—as when unregulated overfishing (often by foreign fleets) spurs bushmeat hunting (14) or when shrimp farming destroys mangroves critical as a nursery habitat for harvested wild stocks.

Connections among food sectors are likely becoming more pervasive as commodity markets become fully global and production expands into new areas, creating complex cascades of interdependencies. To avoid unintended negative impacts, as well as to identify and capitalize on potential winwin opportunities, requires clear, quantitative assessments of both positive and negative linkages among food systems that can, for example, help farmers make informed choices regarding raw material inputs and waste management. Integration of impacts and linkages into comprehensive assessments will also allow policymakers to evaluate new production systems in the context of wider regional and global food systems and sustainability objectives.

Only if researchers provide assessments and methodologies to support an integrative understanding will decision makers be able to anticipate how and where the different dimensions of environmental impacts will change under a given action. Such an approach is vital if we are to achieve increased production and harvest while decreasing the environmental impact of food. It is no longer safe to rely on natural resilience to ensure sustainable food production, given that many buffers to the planet's ecological limits are already close to exhausted (15), and in some regions, local limits have already been surpassed.

Smarter Food Policy

The global food system is too complex, diverse, and contingent on environmental and socioeconomic context to allow for simple or singular policy recommendations. However, because food systems are linked globally through international supply chains and distributed environmental impacts (e.g., greenhouse gases), achieving sustainable food production for 10 billion people will require global-level coordination, through mechanisms such as intergovernmental agreements and trade deals. Such collaboration will need to favor more environmentally efficient forms of production while meeting food security and other sustainable development goals, decisions that require comprehensive and balanced knowledge on the impacts of different food production systems and linkages among them.

Addressing these shortcomings requires three linked approaches: First, funding organizations and researchers should prioritize the collation, collection, and synthesis of spatially explicit primary data on underassessed foods and underassessed impacts for well-studied foods. New studies should be evaluated

for how much they augment existing data, and we suggest prioritizing initial data collection and collation and synthesis of understudied foods and environmental impacts over ever-more refined studies of welldocumented systems. For example, many tropical and arid crops (e.g., sorghum, coffee, and sugar cane) and aquatic species (e.g., inland fisheries and seaweed mariculture) are underassessed and are critical in developing nations.

Importantly, including many underassessed foods in comprehensive assessments is immediately tractable because necessary data often already exist (e.g., country-level production and global-gridded databases of fisheries). Rapid advances in satellite remote sensing and artificial intelligence are already being used for monitoring biodiversity, as well as fishing, farming, and hunting activities. Where data gaps exist, they should be prioritized for expanded monitoring but could be temporarily filled by estimation or simulation. For example, remote sensing and geographic information system data can be integrated into environmental suitability models to predict bushmeat hunting patterns in Central Africa (16). Although some of these approaches are still in their infancy, they are improving as new data and technologies rapidly come online.

Second, the linkages among different foods and aspects of the food system need to be better defined and quantified. International organizations such as the Food and Agriculture Organization and other United Nations agencies are well placed to coordinate and lead such efforts, with the collation and provision of existing datasets being a priority. The quality of these datasets, however, critically depends on the statistical capacities of the reporting countries. In short, these agencies need additional financial support if they are to better track and report linkages among foods. Existing economic and environmental methods have great potential to improve our understanding and documentation of these linkages—for example, the use of hydrological models to predict where eutrophication will impact downstream food production. But again, it is important to restate that even the most sophisticated models today would omit large parts of the global food system because the data underpinning them are underreported.

Finally, we issue an urgent call for national and international policymakers to increase dialogue and the sharing of data and even personnel among departments tasked with different aspects of food systems. We must reverse trends toward decreased

funding for gathering national and subnational food statistics. Coordination and adequate staffing are vital for enabling comparable and comprehensive assessments of food's environmental impacts, understanding trade-offs and synergies among different objectives, and setting sustainable dietary recommendations for consumers. For example, if all Americans followed the US Department of Agriculture–recommended diet, US greenhouse gas emissions from food would actually increase by 12% (17). Although shifts toward alternative diet scenarios have been estimated to reduce landuse and greenhouse gases, the full suite of impacts

(Ext. Data S3) and the linkages associated with feed, including fertilizer and other indirect and localized impacts, have not yet been accounted for in these assessments.

The diversity of food systems, the range of objectives and stakeholders, and the linkages among different components make forward-looking, proactive, and comprehensive food policy a major challenge at all levels from individuals to international organizations. To make effective food policy now and to plan for future scenarios and shifting linkages among food sectors we need a comprehensive baseline understanding that includes all food systems, their direct and indirect connections, and how these are changing. Armed with this information, a wide variety of positive outcomes becomes possible through improving efficiency within particular food systems, favoring positive over negative linkages, encouraging the consumption of low-impact foods, or any combination of these strategies. For example, governments could favor subsidies for low-impact or positive-linkage foods, food companies could develop (and market) foods they know scientifically are more environmentally efficient, and consumers could make better-informed decisions at supermarkets and restaurants. Some of these opportunities are already occurring because of increased awareness of the health and environmental impacts of food, but many are currently missed because of major gaps in assessments of the impacts and linkages in food systems.

We ask policymakers to work toward responsible food production that respects the planet's limits. And we call on researchers to put all foods on the same table in even-handed environmental impact assessments.

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