INSIGHTS

PERSPECTIVES

FOOD

Plating up solutions

Can eating patterns be both healthier and more sustainable?

By **Tara Garnett**

The food system—that is, all the processes involved in feeding the global population—is responsible for ~25% of global greenhouse gas (GHG) emissions. It also drives deforestation and biodiversity loss, land degradation, water overuse, and pollution, and creates and perpetuates inequalities within and across societies. And it does not even feed us effectively: While obesity and diet-related noncommunicable diseases escalate, hunger and micronutrient deficiencies persist. As the global population grows, becomes wealthier, and demands more resource-intensive foods, these problems are likely to worsen. A systemic approach that jointly addresses problems related to production, consumption, and inequity is needed.

So far, policy-makers have mostly adopted a production-based approach to these interconnected challenges, focusing on technologies and strategies that increase food output in ways that do less environmental damage. Cleaner production techniques are clearly essential. But by itself, this "more food with less impact" approach cannot deliver on the deep cuts in emissions needed for the food system to help deliver on the Paris climate commitment (*1*). Nor does it address the systemic imbalances that cause food insecurity, rising obesity and noncommunicable diseases, and high levels of food waste.

Healthy diets may have high environmental impacts—for example, if food is transported by air. Yet, less environmentally damaging diets are not necessarily nutritionally adequate—for example, if they include processed foods high in sugar.

To address these imbalances, policy-makers must also consider the driver of production: human eating patterns. Scientists are now starting to explore these drivers. Could dietary alterations achieve multiple benefits? Is it possible to identify diets that are sustainable and also benefit our health? Almost all researchers who study sustainable healthy diets highlight the high environmental impacts of meat and dairy consumption and the complex associations between high meat intakes and poor health outcomes. But beyond this, their research approaches and scope vary.

Some studies compare the environmental impacts of diets differing in their meat content with those of average national dietary patterns. The nutritional impacts of these diets are not examined; nutritional adequacy is assumed (*2*). Other studies pay closer attention to the health implications of lower-emitting diets, considering either

Food Climate Research Network, Environmental Change Institute, and Oxford Martin Programme on the Future of Food, University of Oxford, Oxford OX1 3QY, UK. Email: taragarnett@fcrn.org.uk

the nutrient contents of differing diets or associations with health outcomes (*3*). An additional approach reverses the question to consider the environmental impacts of healthier diets (*4*–*6*). Linear optimization models seek to identify "best-fit" diets that deliver adequate nutrition at the lowest environmental cost, while maintaining some semblance of normality (*7*, *8*). Finally, a few global studies use life cycle assessment and nutritional epidemiological data sets comparing average diets in different regions with defined "healthy," Mediterranean, vegetarian, and vegan diets (*9*, *10*).

What conclusions can be drawn? Differences in methodologies, data sources, and question-framing muddy the waters. Furthermore, most studies focus on the country level, mainly in Northern and Western Europe. Less affluent country contexts are almost entirely unexamined, barring a few exceptions; for example, studies for China and India confirm the importance of meat consumption as a determinant of overall GHG emissions (*11*, *12*). Global studies are still scarce.

However, findings to date do allow the following observations to be made. The typical Western eating patterns that are growing in prevalence across the world have high environmental impacts and damage health. These "lose-lose" diets are the point of departure when considering the merits of alternatives. Diets containing fewer or no animal products generally emit fewer GHGs than the high-meat Western norm: On average, the lower the animal component, the lower the GHG emissions, although this varies by production context and choice of substitute foods. Conclusions on water impacts are less clear because fruits and vegetables can require high levels of irrigation. Reducing overall energy intakes in line with dietary recommendations also reduces impacts overall.

"Win-win" diets that are less land-, water-, and GHG-intensive than the Western default and that broadly adhere to nutritional guidelines can be identified. Micronutrient deficiencies are a risk, however, and some studies suggest that sugar intakes can increase. To avoid these outcomes, reduced meat intakes need to be compensated for with increases in the quantity and diversity of whole grains, legumes, fruits, and vegetables. Critically, although synergies are possible, they are not guaranteed. Healthy diets may have high environmental impacts if rich in dairy, lean meats, and fresh produce grown under protected conditions or transported by air, while less environmentally damaging diets are not necessarily nutritionally adequate (see the figure).

There are, moreover, many more questions to answer. First, work on sustainable diets does not generally account for differences in production systems. These vary hugely, such as between industrial feedlot beef and sub-Saharan pastoral cattle herds, and have very different impacts. Food processing affects both environmental and nutritional impacts of a given food, as exemplified by chicken breast and bread-crumbed nuggets. Future innovations in production and processing methods could alter the environment-health relationship; for example, lower-impact animal feeds could address some concerns around livestock production. These factors make it difficult to identify an optimal level of animal product consumption.

Second, studies largely focus on only a few environmental aspects. Most assess the impact on GHG emissions; some additionally consider aspects of land and water use. Other environmental dimensions are less examined. Impacts on biodiversity are a notable gap, reflecting difficulties of identifying appropriate metrics, diversity of agroecological production contexts, and perhaps the fact that whereas GHG emission reductions may lead to cost savings, this applies much less to biodiversity protection.

This reliance on just one or a few indicators of sustainability matters because the metrics used influence the conclusions drawn (*13*). For example, poultry has much lower GHG emissions than beef. However, poultry production relies heavily on feeding cereals that could potentially be consumed directly by humans. This is also true of ruminants in the very intensive systems that are increasingly prevalent. But ruminants in mixed and less extensive systems rely more on coarse residues and by-products or on grass from land that may be unsuited to cropping, thereby recycling nutrients and making them available as manure for crops. In certain limited contexts, and provided that they are well managed, grazing animals can also help maintain biodiversity in grasslands.

Third, a full definition of sustainability would include broader societal concerns, encompassing livelihoods, affordability, ani-

Health and environmental impacts of different diets

This figure compares "win-win" diets that are both healthy and have a low environmental impact with other dietary patterns seen around the world today. The typical Western diet, which is both unsustainable and unhealthy, is growing in prevalence around the world.

	Dietary diversity	Food energy intake/expenditure	Animal products	Fish & related	Vegetables & fruits	Whole grains tubers & legumes	Processed foods	Food losses & waste	Cooking fuels
Healthier & more sustainable diets	High	Balanced	Low (all parts eaten)	Low to moderate (sustainable)	High (minimally processed)	High	Avoided	Low	Efficient
Diets of the healthy wealthy	High	Balanced	Moderate to high (lean meats)	High	High	Low to high	Avoided	High (consumer)	Heavy use
Western-type diets (global)	Low	Excessive	High	Low to high (unsustainable)	Low	Low	High	High	Inefficient
Diet of the poor in poor countries	Low	Insufficient	Low	Low	Low	High (legumes often low)	Low (but growing)	High (spoilage) Low (consumer)	Inefficient

GRAPHIC: N. CARY/SCIENCE

mal welfare, and non-nutritional health issues. There will inevitably be trade-offs. For example, livestock intensification may lower GHG emissions per kilogram of meat or milk output but raise animal welfare concerns, increase antibiotics use, or cause local job losses. Additionally, many social and economic objectives are difficult to agree upon and measure. Food should be affordable, but should it be cheap? Is smallholder agriculture or large-scale production preferable? Is equality an end in itself or can its pursuit stifle innovation? How far are radical changes in the workings of the economy possible, legitimate, or desirable?

Some of these questions can be addressed using methodologies drawn from specific disciplines. Attempts are being been made to develop frameworks for incorporating socioeconomic dimensions into environmental life cycle assessment (*14*). This is, however, still a new and evolving area of research. Moreover, not all issues are considered equally important by all—for example, some people care more about animal welfare than others—and visions of what a sustainable food system might look like vary based on individual aesthetics and ideologies.

It is in this arena of values that questions about effecting change become most contested. We know little about how to move eating patterns in healthier, let alone more

"...most studies focus on... Europe. Less affluent country contexts are almost entirely unexamined..."

sustainable, directions, except that education and awareness-raising alone achieve little. This ignorance reflects the chronic privileging of the natural and physical over the social sciences and policy reluctance to interfere with the market, risk votes, or displease powerful corporations.

But if, as evidence suggests, we cannot address our environmental problems without altering diets, we need a research program that encompasses more structural approaches to exploring what mix of regulatory and economic measures, industry actions, and education programs could be effective and acceptable, and at which scales, from local to transnational. Policymakers must also be willing to test promising approaches where evidence is scarce; experimentation builds evidence.

It will also be necessary to investigate possible unwanted rebound effects. Country-level interventions to cut meat intakes may not lead to global emission cuts if national production is maintained and meat exported. Interventions will also affect population subgroups differently. For example, a meat tax could potentially incentivize a switch to fish, with environmental problems swapped rather than eliminated; to refined, nutritionally poor carbohydrates; to cheaper processed, less healthy meat, resulting in no environmental gain and worse health; or to meat with lower animal-welfare credentials. Policy-induced changes in diets may also affect broader nonfood consumption through price rebounds, with knock-on environmental impacts.

Ultimately, to address these questions, researchers need to focus more on the values that underpin food systems research and advocacy (*15*). A critical appraisal of the assumptions shaping our own research questions is warranted. More generally, values frame and inform which issues or options are considered or ignored, which sustainability dimensions prioritized, which interventions considered researchable and fundable, and whose voice counts. These questions go beyond the natural sciences. But since food is entangled in almost every aspect of our lives, understanding how sustainable food systems and diets look and how to achieve them will require deeper collaborations across disciplines and beyond academic boundaries. ■

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NANOMATERIALS

Designer nanorod synthesis

Modified cellulose strands create versatile reactor compartments

By **Andrew Houlton**

One-dimensional (1D) rodlike nanostructures are of fundamental interest for examining size- and shape-dependent phenomena and can have applications that include next-generation electronics and sensing elements (*1*–*3*). The growth of such nanostructures poses considerable challenges for synthetic chemists and materials scientists. However, because few materials naturally grow in such an anisotropic manner, linear pores (molds) or surface templates (such as DNA) are used to guide their formation. On page 1268 of this issue, Pang *et al.* (*4*) describe a highly versatile approach that combines both multicompartmentalization and surface modification using cellulose-based materials and that can control nanorod surface chemistry. This work conceptually extends the level to which chemical reaction space can be designed.

Methodologies for 1D material synthesis must direct growth by defining the reaction space in which product formation occurs. A common approach is to use porous matrices, such as alumina and polycarbonate membranes, as molds (see the figure, left panel) (*5*, *6*). The linear pore channels in these matrices are filled with soluble precursors, such as metal ions, that are chemically transformed into insoluble material that conforms to the pore shape. However, the matrix needs to be removed to isolate individual rods. Diameters have been limited by the range of available pore sizes (tens of nanometers), but the recent development of molecular-based molds may overcome some of these problems (*7*).

The smallest-diameter nanorods have been prepared by using naturally occurring linear biopolymers, such as DNA (see the figure, middle panel) (*8*). The rodlike double helix of individual DNA molecules is

School of Chemistry, Newcastle University, Newcastle, NE1 7RU, UK. Email: andrew.houlton@ncl.ac.uk

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