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SUSTAINABILITY

Transforming the global food system

Can the predicted rise in global food demand by 2050 be met sustainably? A modelling study suggests that a combination of interventions will be needed to tackle the associated environmental challenges. SEE ARTICLE P. 519

GÜNTHER FISCHER

The global population in 2010 was estimated to be 6.9 billion people, and by 2050 is predicted to reach between 8.5 billion and 10 billion people[1]. This increase would bring a corresponding rise in food demand that would affect the environmental toll that food production exerts on the planet. On page 519, Springmann *et al.*[2] report their analysis of the environmental pressures that would arise in a projected scenario for the global food system in 2050. They also modelled the effects of implementing approaches to lessen the environmental consequences of food production.

Food security has long been a challenge for human societies, and is a pressing global issue. Indeed, many targets related to this area are part of the United Nations' Sustainable Development Goals[3], which include eradicating hunger, ending poverty and combating climate change. Achieving a sustainable global food system clearly requires progress on social, economic and environmental fronts.

Springmann and colleagues built a model to assess the projected global demand for agricultural products by 2050 on a country-by-country basis, given the expected changes in population, income levels and dietary preferences by that time. It has been predicted[4] that global income in 2050 will be 3–4 times higher than it was in 2010. The authors' projections of future food consumption were based on established statistical associations between food demands and changes in income or population. These predict that, by 2050, there will be less undernutrition, a shift towards greater global consumption of livestock-based products and a fairly constant intake of staple crops per person.

The authors assessed predicted global environmental impacts for the projected food production by mid-century. They focused on five environmental pressures: the greenhouse-gas emissions associated with agricultural production; the use of land for crop production, given the associated consequences (such as carbon or biodiversity losses) that might accompany land-use changes; the demand for water to irrigate crops; and the application of either nitrogen- or phosphorus-based fertilizers, respectively. It is important to consider fertilizers because of the greenhouse-gas emissions that are linked to their use, and the possibility that they might contaminate soils or aquatic ecosystems.

Springmann *et al.* compared the projected environmental impacts in 2050 to a proposed set of planetary boundaries thought to represent safe operating limits for human activities[5]. For example, the boundary set by the authors for agricultural greenhouse-gas emissions was established in relation to the threshold necessary to keep global warming at a level of 2 °C above pre-industrial levels. However, their limit for emission levels is less stringent than the limit needed to achieve the 1.5 °C target set in the United Nations Framework Convention on Climate Change Paris Agreement of 2015, which was analysed in a recent report[6] by the Intergovernmental Panel on Climate Change. This report details how limiting warming to 1.5 °C rather than to 2 °C above pre-industrial levels would reduce the climate-related risks to health, livelihoods, food security and water supply. On the basis of current food yields and agricultural practices, Springmann and colleagues estimate that, between 2010 and 2050, the environmental impacts of the food system could increase by between 50% and 92% and reach levels that exceed the proposed boundaries[5] for planetary stability.

The researchers went on to assess the effect of possible interventions that could reduce these environmental pressures. These measures relate to managing food demand and raising food-production efficiency in terms of three broad intervention categories.

One intervention category concerns improvements in agricultural technologies and resource management. These could enhance production efficiency and increase crop yields per unit of land, given a particular water and nutrient input. Another category was dietary changes, whereby individuals might limit their meat consumption and move towards plant-based foods. Meat production usually requires a more intensive and environmentally damaging mode of production than that needed for plant-based food[7]. Moreover, limiting meat and sugar consumption and eating fruit and vegetables is aligned with nutrition guidelines for a healthy diet[8]. The third category the authors considered was

BEN NELMES/REUTERS

Figure 1 | Discarded food waste in British Columbia, Canada. This food did not reach consumers.

reduction of food-chain waste from field to plate. It is estimated that up to one-third of food doesn't reach the market (Fig. 1) or is discarded after purchase[9]. Reducing this waste would increase food availability without the need for extra food production.

Springmann and colleagues conclude that an intervention in only one of the three categories they analysed would not achieve planetary sustainability across all five of the environmental domains that they assessed. Instead, a bundle of interventions in all three categories would be needed to ensure that the global food system could be sustainably supported by the planet in 2050. They found that the projected greenhouse-gas emissions from agriculture would not be supportable unless global meat consumption was reduced. They also report that the expansion of cropland and water use would be best counteracted by improvements in agricultural technologies and management approaches that bring farming yields closer to the maximum yield efficiency that is ecologically possible. In addition, their analysis indicates that achieving fertilizer-use reduction would require a combination of measures that improve farming practices and decrease food demand.

There are some caveats regarding Springmann and colleagues' scenarios. For example, they did not take climate-change effects into account in their projections of future agricultural production, and such impacts should be a priority for future analysis. Also, the authors' analysis did not consider the world's grassland areas, even though they represent more than double the area of global cropland[10]. These grassland areas should be considered when setting planetary boundaries for land use. Moreover, Springmann and colleagues' study analyses only the environmental impacts of cropland-based food production — it doesn't assess how to balance these impacts with those in sectors such as energy, transport or industry.

Nevertheless, the authors' analysis is valuable and informative for the discussion about how to achieve a sustainable food system that meets future needs, even if some of the planetary-boundary values they used have large uncertainty ranges[11]. In addition, any proposed interventions should not be implemented using a one-size-fits-all approach. Instead, any regulatory frameworks and incentives will need to be tailored to the needs of a given region, whether this means investments in education, health-service access, land-use regulations or water allocation, for example.

Springmann and colleagues also did not address certain key issues that are needed to develop a resilient agricultural system. The rights of access to land and natural resources, and the long-term security of those rights, is needed to motivate investments by farmers. Farmers could also be helped by improvements in transport, finance and communication infrastructure that enable them to access advanced technologies, minimize their production risks and target their production for local or international markets.

A recent report[12] by the Food and Agriculture Organization of the United Nations concludes that environmental sustainability and food security can go hand in hand by 2050, but that substantial investments are needed to transform the global food system. Political and public commitment will be essential to ensure increases in budgets for the development of international agriculture.

Food demand and food production are two sides of the global food-system equation. Springmann and colleagues' work provides a timely warning that interventions will be needed in both domains to achieve food security in the future, and to ensure that the environmental impacts of the food-production system remain within boundaries that Earth can sustain. ■

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MATERIALS SCIENCE

The war on fake graphene

The material graphene has a vast number of potential applications — but a survey of commercially available graphene samples reveals that research could be undermined by the poor quality of the available material.

PETER BØGGILD

Graphite is composed of layers of carbon atoms just a single atom in thickness, known as graphene sheets, to which it owes many of its remarkable properties. When the thickness of graphite flakes is reduced to just a few graphene layers, some of the material's technologically most important characteristics are greatly enhanced — such as the total surface area per gram, and the mechanical flexibility of the individual flakes. In other words, graphene is more than just thin graphite. Unfortunately, it seems that many graphene producers either do not know or do not care about this. Writing in *Advanced Materials*, Kauling *et al.*[1] report a systematic study of graphene from 60 producers, and find that many highly priced graphene products consist mostly of graphite powder.

Imagine a world in which antibiotics could be sold by anybody, and were not subject to quality standards and regulations. Many people would be afraid to use them because of the potential side effects, or because they had no faith that they would work, with potentially fatal consequences. For emerging nanomaterials such as graphene, a lack of standards is creating a situation that, although not deadly, is similarly unacceptable.

One of the most well-established methods for producing graphene for commercial applications is liquid-phase exfoliation[2] (LPE) — a process that involves milling graphite into a powder, and separating the particles into tiny flakes by applying mechanical forces in a liquid. Those precious flakes that contain just a few layers of graphene are then separated from the rest (Fig. 1). Graphene produced in this way has a huge number of potential applications, including battery technology, composite materials and solar cells. The LPE of graphite was first achieved using sonication to produce the flakes[3], and later work showed that even a kitchen blender[4] can be used to create violent turbulent forces that pull graphene sheets apart without destroying them.

But how thin must graphite flakes be to behave as graphene? A common idea, backed up[5] by the International Organization for Standardization (ISO), is that flakes containing more than ten graphene layers are basically graphite. This seemingly arbitrary threshold has some basis in physics, as Kauling *et al.* note. For example, thermodynamic considerations dictate that each layer of atoms in a flake of ten or fewer layers behaves as an individual graphene crystal at room temperature.