Remodelling the Global Food System for the Anthropocene

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4 November 2021

Summary

The global food system has enabled a ten-fold increase in human population over the past two and a half centuries, but still in 2020 some 770 million people were estimated to be undernourished. At the same time, more than 2 billion are overweight or obese, a result of overconsuming highly processed, energy-dense, but nutritionally deficient foods, which have been linked to diseases that cause more than a fifth of all adult deaths. While under-delivering on healthy and sufficient nutrition for all people, the world's food value chain is placing an excessive and growing burden on its natural foundations. It accounts for 21-37% of all anthropogenic greenhouse-gas emissions. It releases tremendous amounts of reactive nitrogen and phosphorus, leading to dead zones in aquatic ecosystems. It uses vast quantities of water at an unsustainable pace, while allowing 25-30% of totally produced food to go to waste. The mainstream agriculture leads to soil erosion that occurs about 10-100 times faster than new soil formation. It applies a range of chemicals that are detrimental to human health and to wildlife. It drives a large-scale degradation of nature and destruction of biological diversity that undermines vital services with which natural ecosystems support us, including clean water supply, soil formation and maintenance, crop pollination, climate regulation, waste decomposition, and control of diseases and pests.

Science has found that these destructive and harmful practices have gone too far, as they are pushing the Earth system out of the Holocene, the geological epoch characterized by overall favourable climate and environmental conditions that enabled the development of agriculture soon after the end of the last Ice Age. It has been proposed that we have entered a new epoch, the Anthropocene, in which the effect of global human enterprise has been to dangerously approach or even transgress several of the planetary boundaries. These are the upper limits to which the globally integrated human activities can be allowed to drive the key planetary variables now dominated by those activities (such as the atmospheric concentration of greenhouse gases), while remaining outside the risk zone, stepping into which would jeopardize the ability of the food system to support the entire future human population with sufficient and healthy nutrition. The global food sector is, in fact, the main culprit in pushing against the planetary boundaries, as it has already transgressed its quota for five (out of nine) scientifically identified boundaries: biodiversity loss, phosphorus and nitrogen application, greenhouse-gas emissions, cropland use, and freshwater use. Clearly, the escalation of the global climate and environmental crises cannot be stopped and reversed without the wholesale participation of the world's food sector.

The current mainstream practices in the food sector have proven unable to deliver on the overarching objective: to provide reliably sufficient and healthy nutrition for everyone now and in the future, while returning and maintaining the global food system safely inside the planetary boundaries. Thus, a wholly new, transformational approach must be adopted. This can be facilitated by a newly developed framework for coordinated systemic action, based on a broad interdisciplinary synthesis of advanced scientific knowledge about diet-related health outcomes and about the global impact of food production and consumption on climate and the environment. It shows that it is theoretically possible to feed the entire world population projected for 2050 a healthy, calorically sufficient diet, without compromising the stability of the Earth system and the provision of essential ecosystem services. Following this framework, the global action approach should consist of three main prongs: 1) a shift to a healthy diet, 2) a radical improvement in food production practices, and 3) a cut-down of food loss and waste by half from the current values.

A large body of scientific evidence shows that, to promote health above the age of two, diet needs to be rich in a wide variety of plant-based foods (excluding refined grains and starchy vegetables) and can optionally include a small amount of poultry, eggs, seafood, and dairy, with little to no red and processed meat or added sugar/sweeteners. The limited intake or avoidance of animal-source foods is recommended both because they (particularly red and processed meat) are associated with increased incidence of non-communicable chronic diseases and because their environmental impacts are overall far higher than is the case for foods of plant origin.

Since most of the agricultural greenhouse-gas emissions come from producing animal-source foods, the recommended dietary shift alone has the potential to reduce the emissions that would otherwise be released from food production in 2050 by 90%. Going a step further and excluding any meat from human diet, even while keeping some seafood, eggs and dairy on the menu, would be enough to bring the emissions from agriculture down within the safe zone for climate change. Without that step, food production practices would need to be improved and wasting food would need to be decreased sufficiently to compensate for emissions coming from the permissible level of meat production within the scope of the above-recommended diet. However, the advised dietary change alone or even a fully plant-based diet would not suffice to ensure that the food system in 2050 be kept below the planetary boundaries for biosphere integrity and the use of cropland, fertilizers and water, respectively. The food system is therefore required to make tremendous progress on production practices and waste reduction.

Many proven methods that could be adopted readily on a large scale to help meet this formidable requirement already exist and are outlined in the main text. Further scientific and technological development will still be needed. Organizational and policy innovations with sufficient dedicated funding to scale up the solutions at the necessary speed are also essential. While the required transformation is daunting, research tells us that by globally coordinated, strategic and thoughtful, all-hands-on-deck action, there is a good chance to remodel the global food system into an environmentally sustainable, health-promoting and socially just enterprise, but only if we act without delay.

As the Industrial Revolution was just taking off in the 18th century, before its benefits could spread widely enough to raise the general standard of living in the western world to outstanding levels, Thomas Malthus posited that the rate of food production could never keep up with the steep rise of human population, which commonly followed from times of relative food abundance. As a result, Malthus argued, a large part of the population would lead lives of poverty and misery, and ultimately scourges such as famine, epidemics and war would bring the number of people back down in line with the finite food supply.

The Malthusian scenario, which Charles Darwin recognized as a common feature of life in nature and a driver of evolution by natural selection, has since fortunately not materialized in the world population overall. Its size is estimated to have multiplied ten-fold over the past two and a half centuries to the current 7.8 billion people, thanks to numerous scientific advancements, technological innovations, and the resulting industrial-scale intensive agriculture. While this is undoubtedly a gargantuan achievement, being complacent about it would be gravely mistaken.

Although the global food system has so far produced enough food to satisfy everyone's caloric needs, it has never managed to deliver an appropriate amount of food calories to everyone. In 2020, some 770 million people, about the size of the total world population in 1750, were undernourished. Most of them hail from the developing world, but rising inequalities within wealthy countries have made an increasing segment of their citizens lack regular access to food too. Simultaneously, more than 2 billion people are overweight or obese, in part because highly processed, energy-dense but nutritionally deficient foods are often made cheaper and easier to find than fresh and wholesome alternatives. Formerly mainly a developed-world problem, growing overweight and obesity rates are now seen in low- and middle-income countries as well. The overconsumption of heavily processed food high in saturated fat, sugar and salt causes a range of diseases (including heart disease, stroke and diabetes) that kill up to 11.6 million people each year, accounting for more than a fifth of all deaths among adults.

While under-delivering on healthy and sufficient nutrition for all humans, the global food system is placing an excessive and growing burden on its natural underpinnings: the climate, the land, the water, and the biosphere. The world's food-value chain – i.e., farming and associated land-use expansion, together with the activities upstream (provision of inputs such as fertilizers) and downstream of agricultural production (including food processing, packaging, refrigeration, distribution, preparation and waste disposal) – contributes between 21% and 37% of all anthropogenic greenhouse-gas releases, more than any other economic sector. The pace of soil erosion due to common intensive farming and harvesting practices is another big concern, as it outstrips the rate of new soil formation by between 10 and 100 times, having contributed to an estimated loss of one third of the world's arable land in just 40 years up to 2015. The unbridled application of fertilizers on croplands, as well as the discharge of manure from animal farming and of organic waste from sewage facilities, release tremendous amounts of reactive nitrogen and phosphorus, particularly into aquatic ecosystems. The oversupply of these minerals leads to an overload of nutrients, supercharging algal growth, which ultimately causes dead zones in aquatic systems from lakes to coastal regions.

Besides introducing water quality hazards, today's agriculture uses vast quantities of water: it accounts for up to 75-84% of global freshwater withdrawals, thereby significantly reducing the freshwater flows available to natural ecosystems and competing with other human requirements for water, e.g., within the energy sector. Much of the investment of water and other resources in food production is in effect squandered, as 25-30% of globally produced food goes to waste, without which a large portion of associated greenhouse-gas emissions and other polluting releases could also be avoided. In the developing world, the waste results mostly at the harvest stage or immediately after it, whereas as much as 60% of food waste in wealthy societies can occur at the retail and consumption end of the food chain.

Modern agriculture is also a direct source of harmful substances, many of which are used to control weeds, pests and pathogens or promote domestic animal growth, but can damage the health of wildlife and humans, either by direct exposure or by the consumption of food and water containing toxic agrichemical residues. Another major problem is that the target organisms develop resistance to those chemicals. For instance, the amount of antibiotics used for growth enhancement in livestock exceeds that prescribed for human disease treatment and threatens to render this vital arsenal of human medicine much less effective, as pathogenic bacteria genetically adapt to low-level doses used for promoting growth in food-animals, while the discovery of new antibiotics loses pace.

As hinted above, today's mainstream agricultural practices, not least the conversion of vibrant natural ecosystems such as tropical rainforests into agricultural land, are extremely detrimental to nature. They are the main driver of rapid and widespread biological diversity loss, which has approached the levels of five geologically recorded mass species extinction events, the last of which ended the reign of dinosaurs 66 million years ago and cleared the stage for the rise of mammals and ultimately humans. Well-functioning ecosystems that harbour a rich diversity of living forms (biodiversity) provide a wide variety of benefits that are essential to human wellbeing, health and even survival. These benefits are known as ecosystem services and include supply of clean water, formation and maintenance of stable and fertile soils, pollination of crops, regulation of climate, decomposition of waste, and control of diseases and pests. By stripping the living world of its diversity, agriculture jeopardizes the delivery of ecosystem services it depends on, and hence puts its own future on the line. One such case is the steep decline in the biomass and diversity of pollinators across the world, linked to a range of harmful practices (from an unchecked use of toxic chemicals to natural habitat destruction), whereby between $235 billion and $577 billion in annual global crop output is put at risk. Meanwhile, nearly all marine fish stocks have either been harvested at the maximum (60% of all world's fisheries) or unsustainably (33%). Anthropogenic climate change is expected to exacerbate the already precarious situation by acting on top of all other human pressures on the biosphere.

While human history has recorded various instances in which agricultural societies exploited and harmed the natural environment beyond its ability to absorb the damage and replenish the overused resources (a prime example being the ancient Fertile Crescent, home to some of the earliest advanced civilizations, where many of the world's staple crops and livestock were domesticated), those cases were geographically limited and it was at least theoretically possible for the affected populations to move elsewhere. Today, however, the food system is implicated in pushing the entire global environment and climate beyond the relatively stable conditions of the geological epoch known as the Holocene, which began after the last Ice Age ended about 11,700 years ago and was characterized by predictable and favourable climate and environmental patterns, thus being uniquely conducive to crop cultivation and enabling the advent of agriculture. Research in the new field of Earth system science, studying our planet as a complex and evolving assembly of major dynamic interacting physical, chemical and biological components (including the climate system and the biosphere) and their interplay with human activities in aggregate, shows those activities have impacted the whole geosystem so dramatically that it is proposed we are no longer living in the stable Holocene state. Rather, we appear to have entered a new geological epoch, named the Anthropocene, in which humanity constitutes the largest driver of change at the planetary scale. While the Earth system may have resilience, i.e., the capacity to withstand and dampen anthropogenic pressures to an extent, the larger those pressures become, the higher the risk of triggering feedback shifts, destabilizing the Earth system to the point at which it would potentially drift away irreversibly towards a state so different from the hospitable, agriculture-enabling Holocene, that a Malthusian catastrophe scenario of global proportions would be very difficult to avoid.

Since the Holocene is the only global climate and environmental state that we can rely on, with high degree of confidence, to be able to support the current human population size, as well as to accommodate some two more billion people anticipated for 2050 and up to about 11 billion projected for 2100, the world must do everything possible to keep the Earth system in the safe operating state that resembles the Holocene state most closely. To determine what that safe perimeter for the totality of human activities is on the planetary scale, science has identified several variables that serve to track the condition of the Earth system's key properties and processes, among which the climate system and the biosphere are the most fundamental. In turn, for each of the variables (including the atmospheric levels of greenhouse gases and the rate of biological species' extinction) research has determined the range of values representing the precarious zone that can be thought of as dangerously close to permanently undermining life-support systems, and risking to cross tipping points that would push the Earth system down a slippery slope. To enable the world to keep at a safe distance from the imminent danger of permanently shifting from a benign to a malign state of the functions and stability of the Earth system, the planetary boundary framework has been developed. Akin to guard-rails, the planetary boundaries are the upper limits to which the globally integrated human activities can be allowed to drive the key planetary variables now dominated by those activities, while remaining outside the risk zone.

The question that necessarily follows is: Is the world still in the zone of safety? Most worryingly, the answer is: no. Of the nine identified planetary boundaries, four have already been transgressed, namely those for greenhouse-gas emissions, biosphere integrity (including both species' extinction rate and ecosystem functioning), human interference with the global nitrogen and phosphorus cycles (particularly through the application of fertilizers), and the use and conversion of land to serve human needs (transformation of natural forests to human-dominated landscapes). Furthermore, global food production alone has transgressed its quota not only for those four, but also for the boundary on freshwater use. Figure 1 shows that, even if all other economic sectors kept their activities firmly within the planetary boundaries, the global food sector would on its own still dangerously undermine the resilience of the Earth system.

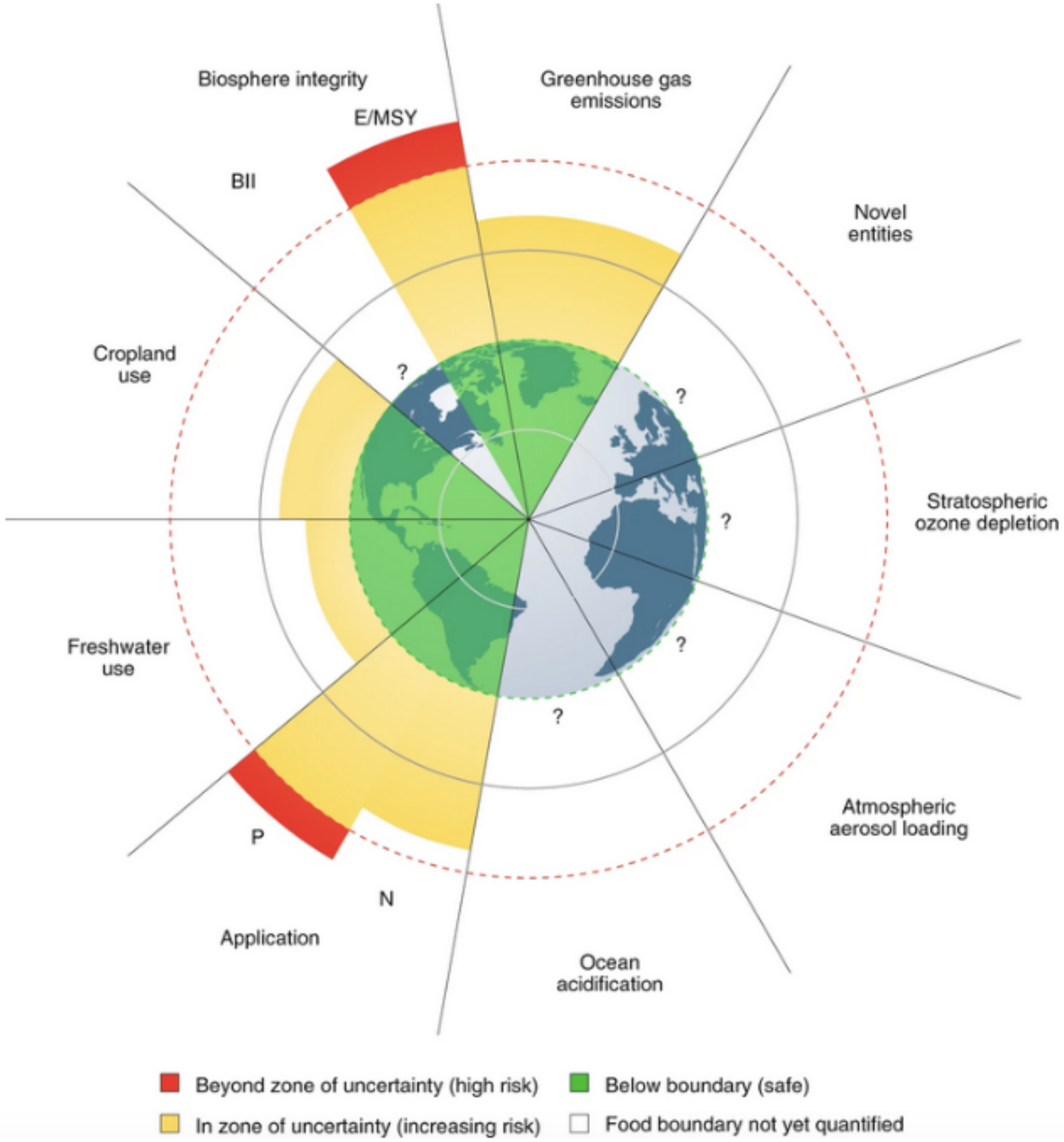

Figure 1. A schematic representation of the planetary boundaries and the extent to which the global food system has transgressed them. *The wedges represent nine key planetary-scale properties and processes that are dominated by the sum of human activities, and are decisive in determining whether the Earth system can hold in a state able to sustain the entire growing human population. So far, only five of those have been quantitatively studied to determine the global food sector's impacts (the rest are labelled with question marks). E/MSY denotes the number of species extinct per million species per year; BII stands for Biodiversity Intactness Index (a measure of population abundance across a wide range of biological groups at the ecosystem level); P is short for phosphorus and N for nitrogen. The inner green dashed line symbolizes the position of the planetary boundaries, i.e., the upper limits to which*

the values of the nine control variables can be increased without risking a dangerous destabilization of the Earth system. The green areas thus correspond to the respective safety zones for the human enterprise. The yellow regions signify the risky range of values for each control variable, associated with the global climate and environmental conditions becoming more precarious, and wherein thresholds or "slippery slopes" into an Earth system state very different from the Holocene are very likely to reside, although their precise position cannot be determined with certainty. Beyond those zones of uncertainty are red spaces, illustrating that a given variable has undoubtedly reached alarming values that can take the Earth system far away from the Holocene-type stability. The lengths of the yellow areas have been normalized, i.e., presented on a proportionate scale, so that the extent to which different variables have transgressed their respective planetary boundaries can be cross-compared. However, the lengths of the green zones are not presented proportionally to the yellow and red regions. Image source: Potsdam Institute for Climate Impact Research, 2019.

Moreover, modelling shows that continuing on the business-as-usual global food system trajectory until 2050 (i.e., keeping the current mainstream food production practices combined with the expected demographic growth and an increasing adoption of modern western-style diets, rich in animal-source foods, by societies around the world) could raise greenhouse-gas emissions, fertilizer application, and cropland and freshwater use by 50-90% compared with 2010, thereby overshooting the planetary boundaries even further.

Clearly, the escalation of the global climate and environmental crises cannot be stopped and reversed without the wholesale participation of the world's food sector. In addition to being comprehensive, the action has to be swift and decisive. The overarching objective is to provide reliably sufficient and healthy nutrition for all the people currently living and for the billions more expected during this century, while returning and maintaining the global food system safely inside the planetary boundaries. As laid out earlier, the current mainstream approach has proven unable to deliver on that objective, and a wholly new, transformational approach must be adopted. Admittedly, this is a daunting task, but it can be facilitated by a newly developed framework for coordinated systemic action, based on a broad interdisciplinary synthesis of advanced scientific knowledge about diet-related health outcomes and about the global impact of food production and consumption on climate and the environment. This framework shows that it is theoretically possible to feed the entire world population projected for 2050 a healthy, calorically sufficient diet, without compromising the stability of the Earth system and the provision of vital ecosystem services.

According to a large accumulation of scientific evidence, the diet that promotes human health above the age of two, and is also compatible with sustaining a well-balanced Earth system, is rich in a variety of plant-based foods (non-starchy vegetables, fruits, whole grains, legumes, nuts, and unsaturated oils) and can optionally include a small amount of poultry, eggs, seafood, and dairy, with little to no red and processed meat, added sugar/sweeteners, refined grains, and starchy vegetables. These basic dietary recommendations are consistent with culinary traditions around the world and could thus be easily implemented in food cultures of different regions. The recent EAT-Lancet Commission report (https://eatforum.org/eat-lancet-commission/) defined this universal dietary composition as a Planetary Health Diet, because it not only maximizes human health but also provides planetary health synergies. The limited intake or avoidance of animal-source foods is recommended both because they (particularly red and processed meat) are associated with increased incidence of non-communicable chronic diseases and because their environmental impacts are overall far higher than is the case for foods of plant origin.

Since most of the agricultural greenhouse-gas emissions come from producing animal-source foods, the recommended dietary shift alone has the potential to reduce the emissions that would otherwise be released from food production in 2050 by 90%. This would position the food system very close to where it needs to be with regard to the associated planetary boundary. Going a step further and excluding any meat from human diet, even while keeping some seafood, eggs and dairy on the menu, would be enough to bring the emissions from agriculture down within safe planetary boundary for climate change. Without that step, food production practices would need to be improved and wasting food would need to be decreased sufficiently to compensate for emissions coming from the permissible level of meat production within the scope of the above-recommended diet. However, the advised dietary change alone or even a fully plant-based diet would not suffice to ensure that the food system in 2050 be kept below the planetary boundaries for biosphere integrity and the use of cropland, fertilizers and water, respectively. The food system is therefore required to make tremendous progress on production practices and waste reduction.

Given that the food sector's encroachment on productive natural ecosystems is the largest threat to biodiversity and ecological integrity (e.g., via forest clearing and biomass burning), any expansion of food production into the remaining area of intact natural ecosystems must be halted, and at least 50% of the Earth's surface must be left undisturbed. In addition to having this large-scale nature conservation perspective of safeguarding key biomes and ecosystems, efforts to preserve biodiversity must also extend to agricultural systems at a fine scale (below 1 km^2), where minimally 10% of the area should be spared for nature to ensure habitat connectivity (so that species can move without impediment across the landscape) and to secure ecosystem services that benefit local food production. Those benefits include, among other things: support for a diverse community of natural pollinators (associated with higher pollination success and increased crop yields), soil erosion mitigation, natural control of agricultural pests, retention of nutrients, carbon sequestration, reduction of flood risk, and regulation of water quality by filtration of agrichemicals and animal waste from runoff. Given the imperative to produce much more food while not expanding the area of cropland, food crops ought not to be grown for the energy sector.

To further alleviate the harmful impacts of food production on the Earth system, and to enable adaptation to the ongoing adverse changes in climate and environmental conditions, agricultural practices must become attuned to the local soil, hydrological and climate characteristics. For instance, it must be recognized that arid regions, where drought conditions are intensifying, cannot continue to rely on dwindling groundwater reserves to support the growth of overly thirsty crops. Those should be replaced by drought-tolerant cultivars with appropriate watering techniques, such as drip irrigation and rainwater harvesting. Generally, indigenous knowledge and traditional farming practices, developed over many centuries and having a record of success in balancing human needs with the needs of natural ecosystems, may provide a basis for the development of locally adapted solutions. Scientific research can take this long-established local knowledge further to build advanced context-specific methods and crop varieties for sustainable agricultural intensification, necessary to produce more outputs with less inputs while coping with growing climate and environmental challenges. An example would be establishing scientific programmes to develop high-yielding varieties of locally acclimated edible plants. Partnering between science and technology developers and local communities would also ensure that the resulting innovations are made culturally appropriate for easy and universal adoption in practice. Considering that most of globally produced food comes from small and medium-size farms, making the innovations affordable is also of major concern.

The damaging effects on the Earth system caused by the agricultural application of nitrogen and phosphorus, which continues to be necessary to attain high crop yields, have to be countered by a range of methods. Nitrogen is abundant in the atmosphere in an inert form, which can be converted into a biologically useful form either naturally, by nitrogen-fixing microorganisms, or industrially, by a process that is energy intensive and hence a large greenhouse-gas emitter. Incorporating the biological nitrogen fixation into agricultural production and supplementing this with fertilization by organic waste (e.g., manure) is thus an important part of a strategy to reduce mineral nitrogen use. At the same time, loss of nitrogen into the natural environment must be minimized. This can be partly achieved by allowing the growth of natural buffer vegetation, which intercepts nitrogen outflow from cropland. Losses of nitrogen can be additionally prevented by avoiding tillage and planting crops with large root mass. Such natural measures also contribute to soil erosion prevention and increasing storage of carbon in soil, which in turn enhances the ability of soil to store phosphorus. It is also very important to stop an excessive use of fertilizers far beyond what is needed to achieve maximum crop yields. This not only unnecessary but harmful practice is widespread in high-income nations, while farmers in lower-income countries cannot afford anything close to the amount of fertilizers necessary to obtain high yields. This situation could be rectified by redistributing fertilizers from regions that use too much to those that have too little. Halting fertilizer overapplication is additionally important for phosphorus as, unlike nitrogen, it is mined from rocks that are in short supply and estimated to run out in 50-100 years under the status-quo exploitation rates.

Any improvements in food production methods must be complemented by a substantial reduction in food waste and overconsumption. In developing countries, where much of food is lost at the harvesting or post-harvesting stage, interventions should focus on equipping the farmers with information, knowledge and infrastructure that would combat the major causes of this food loss. Reliable weather forecasting at sufficient temporal and spatial resolutions should be made easily available, so that harvesting is timed to avoid weather conditions under which crops are likely to be damaged. Knowledge sharing between trusted advisors and farmers about the best practices for handling produce and for livestock hygiene to avoid respective spoilage and contamination should be encouraged. Investments should be made in infrastructure that would enable food to reach consumers in a marketable condition. This may include collective cool and dry storage facilities, simple processing techniques, effective packaging solutions and reliable transport lines for timely access to markets. In the developed countries, where most of food is wasted at the retail and consumption stage, consumers should be educated about effective methods for waste reduction, from the accurate interpretation of ‘best before’ and ‘use by’ labels, to improved purchase planning, storage practices and techniques for utilizing leftovers. Actors at the end of the food value chain, such as grocery stores and restaurants, should analyse their food wastage and adopt appropriate actions to counter it, such as selling damaged produce and food close to expiring at heavily discounted prices, offering reduced portions, and donating unused food in safe condition to charities.

If adopted universally, the recommended predominantly plant-based and health-promoting diet, along with the existing advanced methods for improvement of food production practices that have been demonstrated to work at scale, and the measures to halve global per capita food waste (a target agreed to under the Sustainable Development Goals) have been found to be a powerful recipe for bringing the food system by 2050 close to the safe zone demarcated by the planetary boundaries (Figure 1). Even a small increase in red meat or dairy consumption relative to the recommended levels would make it impossible to bring the food system into the climate-safe zone in 2050. Hence, the suggested dietary shift is vital to making the global food sector climate benign. The dietary change in combination with the most ambitious progress in agricultural production practices and waste reduction would be capable of bringing the cropland use in 2050 beneath the safe maximum as well. The same combination of measures would keep the food-related water use by the mid-century only slightly above the current level, but further water-saving measures in other sectors could help bring global water use to sustainable levels. However, even with the recommended change in food consumption, the largest currently feasible improvements in food production methods and waste cut-down would not suffice to align the food sector with the planetary boundaries for biodiversity loss and the use of fertilizers. Hence, to fully reverse the related detrimental trends, further scientific and technological development will be needed for the discovery and building of novel problem-solving tools that would complement the existing ones. Additionally, the performance of the food sector with respect to the planetary boundaries for atmospheric aerosol loading (e.g., particulate air pollution from biomass burning), novel entities (e.g., agrichemical pollution), ocean acidification, and stratospheric ozone depletion still awaits scientific quantification (Figure 1). Organizational and policy innovations are also essential, if we are to achieve the profound food system transformation at the required speed and scale.

The size and complexity of the task are enormous and without precedent, but failure to accomplish it is not an option, as it would in all likelihood expose humankind to risks of suffering of the sort that Malthus predicted. The international community ought to agree on a set of shared global goals following the best available scientific guidelines. In turn, each country must find a science-based strategy for making its national food system work sustainably both within its specific environmental, economic and social context, and in alignment with the overarching global goals. The tracking of progress at all scales must be enabled by collecting and sharing necessary data at sufficiently high quality and quantity. An integrated approach to solution development must be adopted, because the problems extend not only across geographic and political, but also disciplinary and sectoral confines. Financial mechanisms need to be designed to secure funding in the amount necessary for the success of the endeavour. Special attention ought to be paid to the reality that transformational changes can be particularly hard on certain vulnerable sections of society and economy, which must be offered additional assistance to overcome the difficulties. Research tells us that by such strategic and thoughtful, all-hands-on-deck action, there is a good chance to remodel the global food system into an environmentally sustainable, health-promoting and socially just enterprise, but only if we act without delay.

Key Background Literature

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