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# The Plant-based and Vegan Handbook

## Psychological and Multidisciplinary Perspectives

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# Chapter 30
# Plant-Based v. Omnivorous Diets: Comparative Environmental Impacts

**David Arthur Cleveland and Jennifer Ayla Jay**

## Key Acronyms and Symbols Used

| | |
|---|---|
| ASF | Animal-source food |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide warming equivalent |
| GHG | Greenhouse gas |
| GHGE | Greenhouse gas emissions |
| HSPBD | Healthy, environmentally sustainable, plant-based diet |
| kcal (= Calorie with capital C) | 1 kcal = amount of energy needed to raise the temperature of 1 kg of water 1 °C |
| NCD | Non-communicable disease |
| Nr | Reactive nitrogen, the form used by living organisms |
| PBD | Plant-based diet |
| PBF | Plant-based food |
| $PM_{2.5}$ | Inhalable particulate matter, diameter ≦2.5 micrometers |

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## Introduction: The Anthropocene Crisis and the Global Food System

Since the evolution of modern humans about 200,000 years ago, the last 12,000 years have been the only period with a climate stable enough to support agriculture, which in turn has both encouraged and supported population growth to the current 8+ billion, estimated to increase to almost 10 billion by 2050. The growth rate in human consumption and its impacts on the planet increased with the Industrial Revolution beginning at the end of the eighteenth century and increased further with the Great Acceleration in the growth of the "global socioeconomic system" since the mid-twentieth century (Steffen et al., 2015). There is now increasing evidence that "social and economic systems run on unsustainable resource extraction and consumption" have led to exceeding boundaries for maintaining stability and resilience of the Earth system to support life as we know it (Rockström et al., 2023). When criteria for intergenerational, intragenerational, and interspecies justice to protect humans and other living being through space and time are included in eight Earth system boundaries that have been adequately quantified, seven have already been exceeded, affecting the climate, ecosystems, freshwater availability, and nutrient cycles. Safeguarding Earth system stability and resilience over time by staying within these boundaries is required to protect humans and other living organisms from significant harm.

The result of human impact on the Earth has led many scientists to propose a new geological epoch, the Anthropocene. The term has been adopted to describe the increasing impact of humans across a broad range of physical, biological, and social parameters (Zalasiewicz et al., 2021), and the Anthropocene crisis, now threatens human society, the existence of many species, and the very stability of the favorable conditions that led to agriculture.

Paradoxically, the human behaviors that have led to the Anthropocene crisis are also those that have facilitated humans' biological evolutionary success, defined as increasing population numbers and increasing control and consumption of resources (Cleveland, 2013). Today these behaviors are promoted by the dominant cultural, social, and economic system of neoliberal capitalism, which promotes responding to the Anthropocene crisis by continuing growth in total consumption, only more efficiently, by using fewer resources and creating less pollution per unit of growth. However, this "green growth" in total consumption cannot be completely uncoupled from increased environmental impact, so the absolute amount of resource consumption and pollution would continue to increase, only at a slower rate, failing to avoid Anthropocene catastrophe (Hickel & Kallis, 2020; Jackson, 2016).

Fortunately, there are other evolutionarily selected human behaviors, motivated by values of empathy, altruism, and caring for other living beings that can support sufficient consumption, reducing demand on the environment to avert catastrophe by reducing our environmental pollution and consumption of resources equitably. This will entail reducing superfluous consumption (consumption that does not contribute to well-being) by the wealthier populations that comprise the Global North

(Fanning et al., 2022), as well as stabilizing, and even reducing, the human population. The cultural, social, and economic systems that have led to the Anthropocene crisis must be radically transformed—the main challenge is not technological, but cognitive and cultural—to deemphasize the values that drive increasing superfluous consumption and to emphasize the values that can support sufficient consumption, and that can avoid the catastrophe and lead to human and planetary thriving (Cleveland, 2013).

As documented in this chapter, the global food system is a major contributor to the Anthropocene environmental crisis, as well as the public health crisis—increasing zoonotic diseases and a pandemic of obesity and diet-related non communicable diseases (NCDs). The food system is dominated by animal source foods (ASFs) and ultra processed foods, with high rates of food loss and waste, and negative environmental and health impacts (Fig. 30.1) A major driver of food system impact is the current nutrition transition—a product of powerful multinational food corporations and supportive governments promoting the increased production and consumption of profitable but environmentally destructive, relatively unhealthy ASFs and ultra-processed foods, which replace more environmentally sustainable and healthy foods (Godfray et al., 2018; Swinburn et al., 2019). The food system's negative environmental impacts and their monetary costs are not borne by the food corporations that profit from the food system but are externalized to the present and future society and environment.

Because the food system is a major cause of the Anthropocene crisis, it is also key to resolving it. The large number and mass of livestock animals on the Earth producing ASFs produce a large proportion of the negative impact of food on the environment, though ASFs are not required for a healthy diet. This means that much of the ASFs eaten in the Anthropocene is superfluous consumption. In addition,

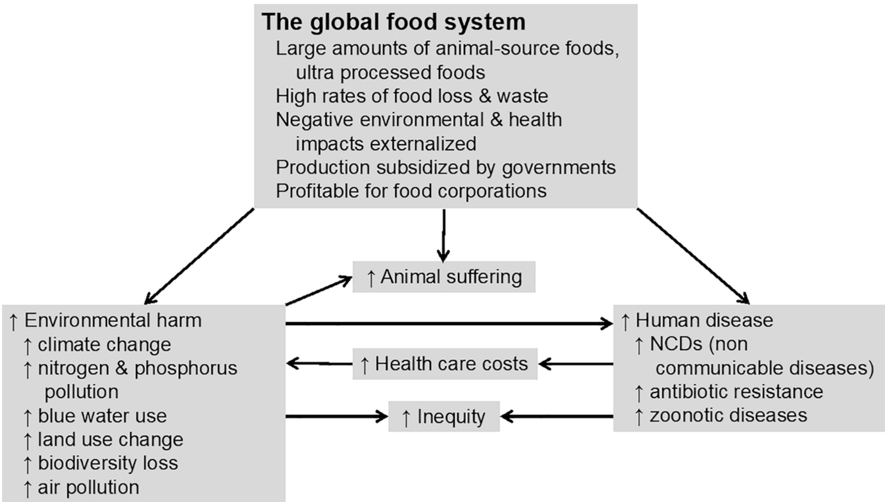


**Fig. 30.1** The global food system. (© 2024, the authors used with permission)

about 10% of energy and 28% of protein in the global human diet are in excess of nutritional requirements (Alexander et al., 2017). A critical part of a successful response to the Anthropocene crisis will be drastically reducing superfluous ASF consumption and production in overconsuming populations, by moving toward healthy, sustainable, plant-based diets (HSPBDs) (McGreevy et al., 2022). A change to more sufficient consumption can greatly reduce environmental impact, doesn't require extensive research, technology development, or resources (Ivanovich et al., 2023), and could increase equity by making resources available to increase consumption to sufficient levels in underconsuming populations.

In this chapter, we compare the environmental impacts of HSPBDs with different omnivorous diets, i.e., those containing ASFs, (including beef, chicken, pork, fish, seafood, dairy, and eggs). We include "healthy" and environmentally "sustainable" in our definition of plant-based diets (PBDs) because some plant-based foods (PBFs), and PBDs, are relatively unhealthy and environmentally harmful. (*Note*: we use "omnivorous diets" to mean diets with significant amounts of ASFs, and HSPBDs to mean diets with all or mostly all PBFs, including vegan diets with no ASFs, vegetarian diets with dairy and/or eggs, and flexitarian diets with small amounts of meat.)

## Environmental Impacts of Plant-Based and Omnivorous Diets

There is some uncertainty in estimates of the impact of the food system, including the differences between PBFs and ASFs, because of lack of data, inconsistency in methods, and differences in the impacts of foods based on their specific contexts. However, a large majority of the growing scientific research on human diets increasingly leads to the conclusion that overall, HSPBDs have much lower negative environmental (and health) impacts than omnivorous diets.

### *Environmental Impacts of Actual and Model Diets*

Animals are on a higher trophic level in the food web than plants. In moving from lower to higher trophic levels there is an increasing use of energy and resources per unit of mass (Bonhommeau et al., 2013), therefore, it is more ecologically efficient to eat plants than to eat the animals that eat the plants. One global estimate is that from crop harvest (including feed crops) through to product available for use, there is an 11.3% loss of energy and 7.6% loss of protein, while for livestock, from inputs (feed, silage, hay, grazed grass) to product available for use, the loss is 87.3% of energy and 81.9% of protein (Alexander et al., 2017). As a result, while ASFs supply only 18% of calories and 37% of protein in the diet, ASF production occupies 77% of all land used for food production globally, about 85% of this for grazing and pasture, and the rest for feed crops (equal to one-third of crop land) (Ritchie &

Roser, 2013). ASFs use other resources less efficiently too. For example, in the US, it requires only about 10% of the environmental resources to produce PBFs with the equivalent amount of energy and/or protein as ASFs (Shepon et al., 2018). The much lower resource use of PBFs is a major reason they are also much less polluting.

Therefore, it's not surprising that analysis of actual and model diets shows that HSPBDs have much lower negative environmental impact than omnivorous diets. For example, analysis of the diets of 29,210 French adults found greenhouse gas emissions (GHGE), energy use, and land use were highest for omnivorous diets and lowest for vegan diets (Rabès et al., 2020). One extensive analysis used impact data from 570 life cycle assessments, accounting for variations in sourcing and production methods, for ~38,000 farms in 119 countries for GHGE, land use, water use, eutrophication risk (dramatic, harmful growth of algae in bodies of water due to influx of nutrients, primarily nitrogen and phosphorus, e.g. from agricultural fertilizer runoff), and potential biodiversity loss (limited to vertebrate species extinctions) (Scarborough et al., 2023). The authors linked these data to diets of a sample of 55,504 vegans, vegetarians, fish-eaters, and meat-eaters in the UK. Results showed impacts for vegans compared with high meat-eaters (>= 100 g total meat consumed per day) were lower by 75% for GHGE, 75% for land use, 54% for water use, 73% for eutrophication, and 67% for biodiversity loss. Low meat eaters also had a large reduction in environmental impact compared with high meat-eaters.

Model diets also show lower environmental impact of HSPBDs. In a review of studies comparing existing diets with modified diets based on those existing diets, HSPBDs with no ASFs showed the highest reduction in GHGE and land use (Hallström et al., 2015). The impacts of global warming in terms of human health, terrestrial ecosystems, and freshwater ecosystems were significantly lower for model vegan diets compared to the Mediterranean diet based on Italian nutritional recommendations (Filippin et al., 2023). A number of studies have shown that the model EAT-Lancet flexitarian diet (a reference diet designed to meet targets for a global food system to promote human health and stay within Earth system boundaries) can reduce environmental impact while improving health (Willett et al., 2019). For example, compared with existing European diets, the EAT-Lancet diet could improve health (measured as reduced mortality and cancer) while also reducing GHGE 50% and land use 62% (Laine et al., 2021).

Food that is lost (pre-retail) or wasted (retail and consumer level) is also an important contributor to environmental impact while contributing nothing to nutrition. Globally, about one-third of all food produced is lost or wasted. Animal foods also contribute greater environmental impacts per unit of food lost and wasted, because of their greater environmental impacts of production. In the US for example, one study found that animal foods were 33% of the mass of food wasted, while the GHGE from this waste was 74% of the GHGE from all food wasted at this level, with ruminant meat accounting for 3% by mass of food wasted, but for 31% of GHGE from waste; in contrast, fruits and vegetables accounted for 33% of waste by mass, but only 8% of GHGE (Heller & Keoleian, 2015).

### *Resolving Confusion About Diets' Environmental Impacts*

Life cycle assessment (LCA) is the method used for most analyses of food system environmental impacts, whether based on empirical data or modeling (Cleveland & Gee, 2017). While the data available for use in LCAs are constantly being improved, they vary in quality, and there are many empirically based and value-based assumptions about what impacts to include, and how they should be attributed to different aspects of a food's life cycle, from the inputs for production, through to post-consumer waste. More empirically based assumptions include e.g. those about what impact data are most accurate, and how to allocate impacts among different products of a process, like milk, meat, or manure. More value-based assumptions include those about how to define system boundaries, e.g., whether to include land use change in the past in estimating impacts of a food, and those about whether to estimate impacts per kcal, grams of protein, or servings. Despite this, a large number of LCAs making different assumptions have shown that HSPBDs have a much lower environmental impact than omnivorous diets.

An important source of variability both between and within LCAs of diets is the wide range of impacts for the same foods, at different spatial scales from local to global, and in different seasons, and by different processes. However, the most comprehensive study of this to date found that despite large differences in environmental impacts of the same foods produced by different entities, ASFs overall have a much higher impact than PBFs (Poore & Nemecek, 2018).

Not accounting for the different roles that different foods play in the diet can also lead to confusion. For example, model diets that replaced some meat with fruits and vegetables on a calorie-for-calorie basis, increased GHGE of PBDs over omnivorous diets (Tom et al., 2015). However, these foods provide different nutrients; plant foods with high vitamin and mineral densities, like vegetables, can have low energy density, leading to high $CO_2$e per kcal, an illustration of why it is inappropriate to substitute foods with very different characteristics on a caloric basis.

Perhaps the greatest contributor to confusion about the impact of different diets is the food industry that profits from selling unhealthy, environmentally unsustainable food, and encourages excess consumption, controls so much of our food environment, and has an outsized influence on governments, civil organizations, and university researchers (Nestle, 2018; Swinburn et al., 2019, p. 32). This includes ASF industries that influence public policy and scientific research to suppress information about the negative environmental impact of ASFs, for example in the US in dietary guidance by government and professional nutrition associations (Rose et al., 2021). Also in the US, the beef industry has a major campaign to convince the public that beef is environmentally sustainable, funded by the US government, and funds research, e.g. at the University of California, that promotes beef (Fassler, 2023).

### *Disentangling the Diet, Environment, Health, Equity Nexus*

PBDs, including those with no ASFs, can be healthier than standard omnivorous diets, while also reducing environmental impact (WHO, 2021). However, while there is a lot of overlap between healthy and environmentally friendly foods (Clark et al., 2022), not all PBDs are healthy, e.g., ultra-processed PBFs (Anastasiou et al., 2022). One study of 100 dietary patterns found that reduced GHGE from diets was associated with poorer health indicators, because some low GHGE diets low in animal foods, saturated fat, and salt, are also low in essential micronutrients, and high in sugar (Payne et al., 2016). Sugar is a plant food with relatively low environmental impact, but current levels of consumption of added sugar, as in sugary beverages like soda and coffee drinks, increase the risk of NCDs including diabetes, liver and heart disease, and dental cavities (Huang et al., 2023).

In addition, there are trade-offs, because ASFs can have higher levels of some bioavailable nutrients than comparable PBFs (Beal et al., 2023), and nutrients in ASFs are a critical part of the diet of some populations, like nomadic herders. In populations obtaining most of their energy from starchy carbohydrates, the addition of meat "or other major protein sources," e.g., legumes and nuts, "is likely to mitigate micronutrient deficiencies and have metabolic benefits by reducing high glycemic load" and improve overall health, for example in the EAT-Lancet diet (Willett et al., 2019, p. 10).

Overall, however, increasing PBDs are critical for increasing equity, because the diminishing resources for production and sinks for pollution in the Anthropocene means that high and increasing consumption of ASFs by wealthier populations results in fewer resources available for low-income, under consuming populations (Cleveland, 2020). These populations can also be exposed to more water, soil, and air pollution from ASF production because a larger proportion of them often live near polluting animal food production facilities (e.g. Lenhardt & Ogneva-Himmelberger, 2013).

## Climate Change

Climate change is one of the most critical of human environmental impacts, "a threat to human well-being and planetary health" with "a rapidly closing window of opportunity to secure a livable and sustainable future for all" (IPCC, 2023, p. 25). The food system accounts for one-third of all anthropogenic GHGE driving climate change (Crippa et al., 2021), and about 57% is from ASFs, 29% from PBFs, and 14% from other sources (Xu et al., 2021). The potential of HSPBDs to mitigate climate change is even greater than suggested by these estimates because large amounts of carbon can be sequestered when land is reverted to natural vegetation from grazing and feed production (Hayek et al., 2021).

While $CO_2$ emissions from fossil fuels have had the largest climate warming effect, other greenhouse gases (GHGs) play a major role, especially methane, which accounts for about 30% of global warming. The different warming impacts of non-$CO_2$ GHGs, and of all GHGs combined, are expressed as $CO_2$ equivalents ($CO_2$e). Animal food production emits a large proportion of methane which has a 100-year climate warming potential of 28 times that of $CO_2$, but a 20-year global warming potential of 81 times that of $CO_2$ because of its short life span in the atmosphere (Smith et al., 2021, p. 16), therefore, reducing methane emissions over the short term is critical. ASFs accounted for 69% of food system methane emissions in 2020 (based on Ivanovich et al., 2023). The food system is also a major source of nitrous oxide, another powerful greenhouse gas that has a 100-year warming potential almost 273 times that of $CO_2$ (Smith et al., 2021, p. 16), and ASFs account for 59% of global nitrous oxide emissions (based on Ivanovich et al., 2023).

An analysis of 120 publications found that at the global level, ruminant meat had the highest $CO_2$e per serving, per gram of protein and per kcal, e.g., over 250 times as much $CO_2$e as legumes per gram of protein, mostly due to methane (Tilman & Clark, 2014). A comparison of the climate impact of Mediterranean, U.S. Healthy, U.S. Current, Healthy Vegetarian, and Vegan diets for the U.S. found kg $CO_2$e/person/day of 3.42, 3.33, 3.19, 1.57, and 0.72 respectively, with ruminant meat the largest contributor of $CO_2$e to the three omnivorous diets, and dairy the largest contributor of $CO_2$e to the vegetarian diet (Jennings et al., 2023).

If the current growth in GHGE of our food system continues, food system emissions will surpass the total allowable GHGE *from all sectors* needed to stay below 1.5 °C of warming (Clark et al., 2020). Reducing food system emissions by achieving 50% of the potential for adoption of HSPBDs, along with higher yields, reduced waste, and high efficiency, is needed for a 67% chance of staying below 1.5 °C. With 100% compliance for all these strategies, food system net cumulative emissions could become zero by dramatically lowering emissions, or even negative due to sequestering carbon on abandoned croplands.

Although pasture-raised (grass-fed) beef is being promoted as a climate solution, net benefits are likely to be quite modest (Garnett et al., 2017). Any climate benefits of grazing are specific to local contexts, limited by the capacity of the soil to sequester carbon, and the amount of carbon already in the soil, and stored carbon can be quickly released by poor management, natural events such as droughts or fires, and by land-use change (Godfray et al., 2018). Evaluating the effect of grass-fed beef on the climate must also include the potential alternative uses of grazing land when cattle are removed. One global analysis found that shifts to HSPBDs by 2050 could enable sequestration on former grazing land of $CO_2$ equal to 99–163% of the $CO_2$ emissions budget required for a 66% chance of limiting warming to 1.5 °C (Hayek et al., 2021).

## Nitrogen (N) and Phosphorus (P) Use and Pollution

N and P are both nutrient elements required for living organisms and are common in crop fertilizers. Even though our atmosphere is 80% inactive nitrogen gas, plants require reactive nitrogen (Nr) that can participate in biological processes, and the transformation of nitrogen gas to Nr, a process called nitrogen fixation, is a limiting factor for food production. Until the early twentieth century, this process was mostly through soil bacteria and cultivation of N-fixing plants, like legumes, when the Haber-Bosch industrial process was invented, which converts nitrogen gas to ammonia, a form of Nr, via a chemical reaction under high pressure and temperature. Today about 70% of the Nr used in food production is from the Haber-Bosch process, contributing about ~40% of dietary protein in the human diet. (Galloway et al., 2003, p. 345).

Only about 50% of the Nr in fertilizers used for crop production is incorporated in the crops, while the other 50% pollutes the environment through leakage into the soil, water, and atmosphere, causing major disruption of terrestrial and aquatic ecosystems, leading to reduced biodiversity, acidified surface waters, and emissions of the GHG nitrous oxide. Nitrate, a common N compound polluting drinking water, is a major health problem, and N-containing compounds from fertilizer and other sources in the lower atmosphere contribute to ozone and smog, important causes of respiratory illness (Galloway et al., 2003).

While the source of Nr for crop production is the air, the source of P is mining a small number of global mineral deposits which, with rapidly increasing demand for P fertilizers, will be exhausted in several generations, and the remaining deposits are lower quality and more expensive to mine (Vaccari et al., 2019). Like Nr, P use in crop production is very inefficient, with only about 15% of P mined is consumed as food (Vaccari et al., 2019). Thus, increased efforts to recover P from agricultural and municipal waste streams are critical for global food security.

N and P often contaminate surface waters, mostly through runoff from agricultural fields, due to inefficient fertilizer application and use by plants, and animal waste (Bechmann & Stålnacke, 2019). In many aquatic systems, either N or P is the "limiting nutrient," so that that contamination by field runoff stimulates algal growth, leading to eutrophication. When the algae die, decomposing bacteria use up oxygen in the water, resulting in "dead zones." Reducing agriculture's impacts on biogeochemical cycling includes applying N and P fertilizers optimally with respect to type, amount, location, and timing.

ASFs account for much more N and P use and pollution than PBFs. A global estimate of N and P in animal manures in 2011 was equal to the amount used in synthetic N and P fertilizers (Liu et al., 2017). Estimates for P use in Germany agriculture range from 1.4 and 2.7 g of P per kg of food for fruits and vegetables, to 5.3 g for grains and 10 g for vegetable oils, while for animal products it ranges from 10 g of P per kg of food for eggs, up to 70 g for butter and 98 g for beef (Meier & Christen, 2013). In the US ASFs contribute 70% of N and 80% of P leaked to the environment from the food system, with beef alone accounting for 40% and 50%

respectively (Metson et al., 2020). Nitrogen pollution for plant foods range from 0.0 and 2.8 kg N loss per kg for oil and starchy roots up to 16.1 g N loss per kg for pulses (legumes), while for animal products the range is from 20.4 for milk to 234.0 g N for beef (Leach et al., 2017).

## Blue Water Use

The water footprint has three components: blue water (fresh surface and groundwater), green water (rain water that is evaporated or transpired through plants), and gray water (water needed to dilute polluted water to harmless levels). Production of ASFs accounts for 75% of land use change for agriculture, which leads to losses of green water, and lower soil moisture which degrades ecosystems (te Wierik et al., 2021).

Blue water for irrigated crop production diverts it from supporting healthy ecosystems. Globally about 70% of blue water use is for agriculture, with over a third for livestock (98% of this for feed crops) (Mekonnen & Hoekstra, 2012). In the arid western US diversion of surface water greatly increases instances of risk of local extinction for fish species, with 70% of these instances due to diversion for irrigating cattle feed crops (Richter et al., 2020). The Colorado river basin is a major source of water in this region, but it has been drastically depleted over years of overuse, and now by climate change-related prolonged drought: 70% of the Colorado River withdrawn is used for agriculture, 71% of this (or 56% of the total) to irrigate feed for beef and dairy cattle (Richter et al., 2020).

PBFs have a much lower water footprint than ASFs. For example, the combined blue, green, and grey water footprints per kg of beef, chicken, eggs, and milk are 48, 13, 10, and 3 times that of vegetables, and even the combined water footprints of just the protein content of these foods is 4.3, 1.3, 1.1 and 1.2 times that of vegetable protein (based on Mekonnen & Hoekstra, 2012).

## Land Use Change and Biodiversity Loss

In 2017 there were more than 30 billion terrestrial vertebrate livestock animals (82% poultry) in the world (four times the number of humans), with 75 billion slaughtered annually (95% poultry) (FAOSTAT, 2019). This large and growing population of domestic food animals is replacing wild animals, with one estimate that 85% of wild mammal biomass has been lost, with livestock biomass now 14 times that of wild mammals, and 1.7 times that of humans (Bar-On et al., 2018).

The large number of animals required to produce ASFs for high and rising consumption is a major cause of land use change, driving the alarming loss of biodiversity through habitat loss, with extinction rates about 1000 times the background rate, the 6th mass extinction in the Earth's history (Machovina et al., 2015). For example, in Mexico, increasing ASFs in the diet has led to environmentally damaging land use change (Tello et al., 2020). Over 37% of the Earth's ice-free land surface is used for agricultural production, of which livestock production accounts for about 75% (which includes one-third of cropland used for animal feed) (FAOSTAT, 2019). While the effect of grazing domestic animals can increase biodiversity in some circumstances, the overall effect is a large loss of biodiversity (Filazzola et al., 2020). Increasing ASF consumption and production continue to drive land use change, e.g., in the Amazon, an area uniquely rich in biodiversity, three-quarters of the deforested land has been converted to livestock grazing and feed crop production (Machovina et al., 2015). Land use change is often fragmented, which increases habitat destruction including because areas bordering a developed area are also impacted.

## Air Pollution

Air pollution is currently the most significant environmental risk factor for decreased human health globally, and agriculture is a major source. Exposure to atmospheric particulate matter, 2.5 micrometers or less in diameter ($PM_{2.5}$), is the largest contributor to premature death due to cancer, stroke, and cardiovascular disease, and global $PM_{2.5}$-related emissions from the food system are linked to 23% of the 3.9 million $PM_{2.5}$-attributable premature deaths per year (Balasubramanian et al., 2021). $PM_{2.5}$ may be emitted directly (primary $PM_{2.5}$), or it can be formed in the atmosphere by various precursors including ammonia. Globally, ASF production (manure management and grazing) accounts for 60% of ammonia emissions (Balasubramanian et al., 2021).

In the U.S., agricultural production results in 17,900 deaths per year due to impaired air quality, with a greater number attributable to ASFs v. PBFs per kg, per serving, per kcal, and per g of protein, except for per g protein for fruits (Domingo et al., 2021). Primary $PM_{2.5}$ from agriculture including tillage, fuel combustion for farm equipment, livestock dust, and burning of fields comprises 27% of this pollution, and secondary $PM_{2.5}$ from ammonia emissions 69%, mostly from livestock waste and fertilizer application. Reducing ASFs via HSPBDs, e.g. a vegan, vegetarian, or flexitarian (EAT-Lancet) diet, would reduce deaths from agricultural $PM_{2.5}$ by 68%, 76%, and 83%, respectively (Domingo et al., 2021).

## Diet-Related Disease and the Impact of Health Care

Eating ASFs, especially in the large and growing quantities consumed today, is not required for human health, and is associated with a number of NCDs. Globally, unhealthy diets (low in fruits, vegetables, legumes, whole grains, nuts, and seeds, and high in red and processed meat) are among the top three risk factors for poor health (along with tobacco use and air pollution) (Murray et al., 2020). The pandemic of NCDs contributes to rapidly rising health-care costs which could reach $47 trillion annually by 2030 globally (Bloom et al., 2011), and a total of $95 trillion, or $265,000 per person, for 2015–2050 in the US (Chen et al., 2018).

An important, often overlooked, environmental impact of these unhealthy diets is the health care associated with diet-related disease. For example, in 2018 GHGE from health care in the US were about 553 metric tons of $CO_2e$, 8.5% of total US emissions, and the combined effect of GHGE, $PM_{2.5,}$ and ozone pollution from health care resulted in 388,000 DALYs (disability-adjusted life years, or years lost to premature mortality and disability due to illness) (Eckelman et al., 2020).

A modeling study compared the standard American diet (SAD) to a healthier diet that eliminated red and processed meat (with no change in other ASFs), and increased fruits, vegetables, whole grains, beans, and peas (Hallström et al., 2017). This diet would reduce relative risk by 20–45% for the three diseases examined (colorectal cancer, type 2 diabetes, coronary heart disease), and associated health care costs $93 billion/year (equal to 42% of the total health care costs of these diseases).

This reduction in health care costs would in turn reduce GHGE by 84 kg/capita/year. While this reduction in GHGE from health care is a small portion of GHGE from ASFs in the SAD, and even smaller portion of a typical U.S. resident's total, due to lack of data the healthier diet did not include reductions in other diseases (e.g. hypertension, stroke, other cancers) linked to ASFs, which would reduce GHGE further.

## The Food System, the Environment, and Human Infectious Disease

As we have seen, the scale of animal agriculture has huge effects on the environment, which negatively affects human health. In addition, the widespread use of antibiotics in producing ASFs is causing an increase in antibiotic-resistant pathogenic bacteria, and the ongoing conversion of natural habitats driven by ASF production, and the large, dense concentration of farm animals are driving increasing prevalence of zoonotic infectious disease. The resulting increase in human disease and associated health care costs add to the environmental impacts of ASFs, along with those from the health care costs for diet-related NCDs.

### *Antibiotic Use and Antibiotic-Resistant Bacteria*

The development of antibiotics over the twentieth century led to large improvements in human health. However, widespread use of antibiotics in animal agriculture is reducing their efficacy by increasing the prevalence of antibiotic-resistant bacteria. In fact, according to the World Health Organization, antibiotic resistance is "one of the biggest threats to global health, food security, and development today" (WHO, 2020).

In 2017 73% of all antibiotics used globally were in ASF production, mainly in low doses to promote growth, with an estimated 99,502 tons of active ingredient used in animal agriculture in 2020, projected to increase 8% by 2030 (Mulchandani et al., 2023). This creates a selection environment in farm animals that favors antibiotic-resistant bacteria, which therefore multiply faster than those without resistance.

Manure from industrial food animal production contains high levels of antibiotic resistant bacteria, which can contaminate surface and groundwater, and the air (Sanchez et al., 2016), and be exported from farms as commercially available fertilizers (Cira et al., 2021). A growing number of studies find adverse health impacts associated with living in proximity to livestock operations and manured fields. Livestock workers have been found to be five times more likely than controls to test positive for Methicillin-resistant *Staphylococcus aureus* (MRSA) (Ye et al., 2015).

It has been shown repeatedly that after antibiotics were licensed for use in animal agriculture, the proportion of antibiotic-resistant bacteria resistant to those antibiotics increased in humans. For example, the bacterium *Campylobacter jejuni* is a frequent cause of human gastrointestinal infection and is commonly found in domestic animal feces. Before 1990, the proportion of these bacteria in humans resistant to fluoroquinolone was less than 5%, but after fluoroquinolones were licensed for use in farm animals in 1990, this increased to 50% by 1993, and over 80% by 1996 (Silbergeld et al., 2008).

## *Animal Agriculture and Zoonotic Diseases*

According to the UN, "Over the last 60 years, the majority of new zoonotic pathogens have emerged, largely as a result of human activity, including changes in land-use (e.g. deforestation), and the way we manage agricultural and food production systems" (Maruma Mrema, 2020, p. 2). As discussed above, animal agriculture accounts for the large majority of land use change currently and in the past, leading to a loss of habitat for wildlife and increased contact between humans and disease vectors, both of which can result in increased transmission of zoonotic pathogens.

Industrial agriculture continues to replace traditional farming, including facilities that confine animals in high densities. The lack of fresh air, insufficient space, inability to perform normal activities, and long-distance transport for slaughter leads to decreased well-being and increased stress, lowering immune response and increasing the ability of pathogens to pass through many animal hosts, which facilitates the evolution of greater pathogenicity (Jones et al., 2013). For example, avian influenza virus that produces only mild symptoms can be transmitted extensively among poultry populations, facilitating its evolution into a highly pathogenic avian influenza capable of human-to-human transmission (Dhingra et al., 2018).

Similarly, large, dense swine populations on farms have been associated with elevated prevalence of swine influenza, and evidence shows that pigs can host viruses from humans and birds along with swine viruses, allowing horizontal transfer of the genes between viral populations that can result in strains capable of transferring between species (Baudon et al., 2017).

## How Can We Increase HSPBDs to Address the Anthropocene Crisis?

Increasing awareness of the negative environmental impacts of ASFs in omnivorous diets will be one critical aspect of motivating adequate responses to the Anthropocene crisis, through both bottom-up changes by individuals, and top-down changes by schools, universities, governments, businesses, and other institutions.

### *Information*

Information about the environmental impact of foods and diets can motivate individuals to change food choices, especially when this information resonates with or changes values. An experiment with US consumers showed they lacked knowledge of the GHGE of foods, underestimated this the most for animal foods, and when provided labels with information on the GHGE of canned vegetable and beef soup, they chose the vegetable soup with lower emissions more often (Camilleri et al., 2019). A randomized control trial in France found that front-of-package traffic light labeling of environmental impact led to participants choosing less meat-based and more vegetarian meals (Arrazat et al., 2023).

Reaching young people, e.g., in educational settings, is especially important because this can affect food choices over lifetimes while contributing to institutional goals for reducing climate and environmental impact (Cleveland & Jay, 2021). A US experiment compared the effects of two, two-quarter courses on university student food choice, a control course on cosmology, and a treatment course which provided information on the climate effects of ASFs (Jay et al., 2019). Students in the control reported no change in diets at the end of the course compared to the beginning of the course, while students in the treatment reported diets at the end of the course that were 17% lower in kg $CO_2$e than at the beginning, mostly due to lower beef consumption, which declined from 3.5 to 2.5 servings/student/week. Similarly, US students who took a one-unit Foodprint seminar reported significantly increased vegetable intake and decreased ruminant meat intake relative to control course students and reduced dietary GHGE 14% (Malan, 2020).

## *Food Environments*

Food environments are important determinants of food choices, and institutions can change these environments to include a larger proportion of PBFs, with the goal of reducing environmental impact. The dining service at one university substituted vegan mayo for egg-based mayo in all its foods after testing to assure that gustatory and physical properties were the same, which reduced $CO_2$e 43%, blue water use 77%, reactive nitrogen use 98%, and land used 63% (Cleveland et al., 2021). At another university, eliminating beef 1 day a week in campus dining halls reduced their $CO_2$e food emissions by 20% (Cleveland & Jay, 2021).

Institutions can also nudge people toward PBDs by changing the way choices are presented, e.g., exploiting the tendency to accept a default. A recent study showed that by offering a plant-based meal as the default compared to a meat-based meal as the default, invitees to campus events choosing plant-based meals increased from 18% to 66%, which decreased GHGE, land use, and nitrogen and phosphorus pollution 39–43% (Boronowsky et al., 2022). However, major progress on college campuses toward environmentally sustainable food systems requires higher education institutions to relinquish neoliberal business policies in favor of the public good (Cleveland, 2023).

Because the development of dietary knowledge, attitudes, and habits in college can persist long after graduation (Movassagh et al., 2017), more healthy plant-based food environments on campus can positively affect health and the environment in later years (Hu et al., 2016). For example, a prospective cohort study that followed young adults over 30 years found that an increase in nutritional quality of plant-centered diets was associated with statistically significant lower risk of type 2 diabetes, weight gain (Choi et al., 2020), and coronary vascular disease (Choi et al., 2021). In turn, improved health from more plant-based diets will reduce GHGE from the healthcare system over time (Hallström et al., 2017), and reduced health care in general will reduce a range of healthcare system environmental harms (Lenzen et al., 2020).

## *Prices*

Taxing or subsidizing foods based on their environmental impact has much potential, and there are some successful examples. The government of Denmark taxed saturated fat from October 2011 to January 2013 to improve health, which resulted in a 4.0% reduction in saturated fat intake, as well as a decrease in salt, and increase in vegetable consumption for most people (Smed et al., 2016). Since most saturated fat in the diet is in animal foods, this tax would also decrease environmental impacts.

A modeling study found that taxing food based on climate impact globally and using tax revenues to increase the availability of fruits and vegetables, could avoid 509,480 deaths, and reduce GHGE by 8.6% in 2020 (Springmann et al., 2017).

Two-thirds of the GHGE reduction was due to reduced beef consumption and one quarter to reduced milk consumption, with a 40% increase in beef cost leading to almost 15% reduction in consumption.

## Conclusion

In the Anthropocene epoch, it has become clear that our dietary choices are existential choices. To feed a human population of 10 billion equitably in 2050 while staying within the sustainable Earth system boundaries requires a major shift toward HSPBDs, in addition to reducing food loss and waste, and improving the efficiency of agricultural and food processes.

Although there is some uncertainty about the details of the environmental impact of diets, understanding the well-documented greater negative environmental, health, and equity impacts of standard omnivorous diets compared with HSPBDs can lead to needed changes in behaviors and policies. The rapid, radical cultural and social changes required include replacing neoliberalism's values that promote superfluous consumption, with scientific understanding of the role of ASFs in the Anthropocene, and the need for rapid and radical change to emphasize the values of sufficiency, community, and compassion. Replacing excess consumption in overconsuming populations with sufficient consumption is also essential for increasing equity by enabling under consuming populations to have access to the food production resources and the food needed for HSPBDs.

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