ANNUAL REVIEWS

Annual Review of Environment and Resources

The Diet, Health, and Environment Trilemma

Michael Clark,[1] Jason Hill,[2] and David Tilman[3,4]

[1]Natural Resources Science and Management, University of Minnesota, St. Paul, Minnesota, 55108, USA; email: maclark@umn.edu

[2]Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, Minnesota, 55108, USA; email: hill0408@umn.edu

[3]Department of Ecology, Evolution, and Behavior, University of Minnesota, St. Paul, Minnesota, 55108, USA; email: tilman@umn.edu

[4]Bren School of Environmental Science and Management, University of California, Santa Barbara, California, 93117, USA

Annu. Rev. Environ. Resour. 2018. 43:109–34

The *Annual Review of Environment and Resources* is online at environ.annualreviews.org

https://doi.org/10.1146/annurev-environ-102017-025957

Keywords

diet, environment, health

Abstract

As populations become more affluent and urbanized, diets are shifting such that they are becoming higher in calories and include more highly processed foods and animal products. These dietary shifts are driving increases in diet-related diseases and are also causing environmental degradation. These linked impacts pose a new key issue for global society—a diet, health, and environment trilemma. Recent dietary shifts have contributed to increasing diet-related health and environmental impacts, including an 80% increase in global diabetes prevalence and an 860% increase in global nitrogen fertilizer use. Furthermore, if current dietary trajectories were to continue for the next several decades, diet-related diseases would account for three-quarters of the global burden of disease and would also lead to large increases in diet-related environmental impacts. We discuss how shifts to healthier diets—such as some Mediterranean, pescetarian, vegetarian, and vegan diets—could reduce incidence of diet-related diseases and improve environmental outcomes. In addition, we detail how other interventions to food systems that use known technologies and management techniques would improve environmental outcomes.

Contents

INTRODUCTION

Global agriculture and the global food production system are essential for human survival and prosperity, but they also contribute to poor health and environmental degradation. Nearly 800 million people are undernourished globally, and more than 2 billion people are overweight (classified as body mass index (BMI) > 25) or obese (BMI > 30) (1, 2). Global agriculture emits 25–33% of global greenhouse gases (GHGs) (3), occupies 40% of Earth's terrestrial surface (**http://www.fao.org/faostat/en/#home**), is the single greatest cause of extinction risk globally (4), is the major cause of eutrophication of freshwater and marine ecosystems because of fertilizer runoff (5), harms health through reduced global air quality (6, 7), and accounts for more than 70% of global freshwater withdrawals (8).

The links between diets, human health, and environmental degradation—known as the diet, health, and environment trilemma—comprise a series of interconnected problems confronting every society globally. Moreover, these problems are on a trajectory to become progressively more severe during the coming decades, especially in developing nations, because dietary shifts toward less healthy and less sustainable diets are tightly associated with increased affluence and urbanization. Also, because diets are socially, economically, and culturally important, solutions to the diet-health-environment trilemma must be consistent with the social, economic, and cultural values of each country or region.

In this review, we first summarize and evaluate the data that describe the magnitudes and trends of each of the three components of this trilemma: (*a*) dietary shifts over the past few decades and the associated health and environmental outcomes; (*b*) the environmental and health impacts of different types of foods; and finally, (*c*) the future human health and environmental harm that

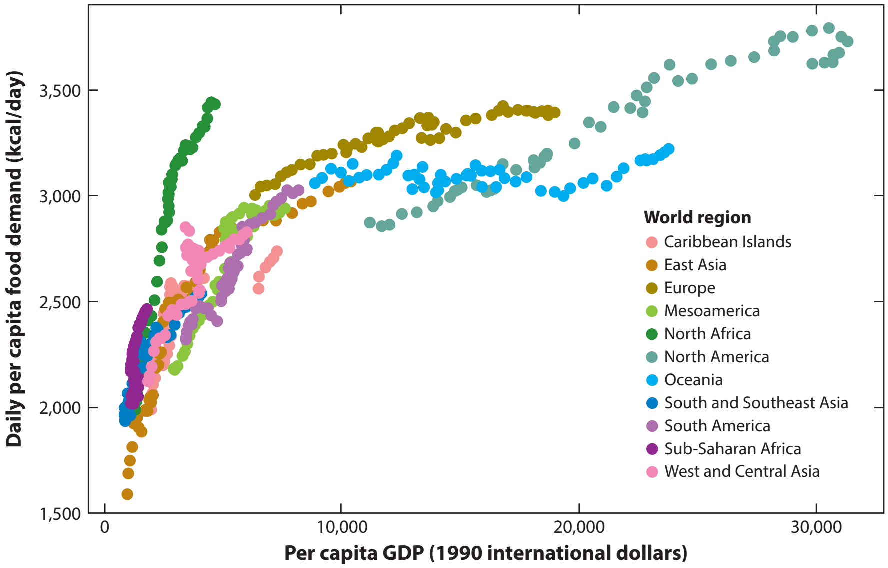

Figure 1

Relationship between per capita income and daily food demand. Data span 1961 to 2013 and are aggregated into 11 world regions. Each point indicates per capita food demand and per capita GDP purchasing power parity in a given year, for each given world region. Per capita GDP purchasing power parity is measured in 1990 international dollars, which indicate per capita wealth after being adjusted for prices in different countries. Per capita food demand is measured as the amount of food that enters the household per day. Per capita food demand is higher than per capita consumption because it does not account for household food waste. Per capita food demand data is from FAOSTAT (**http://www.fao.org/faostat/en/#home**); per capita GDP purchasing power parity is from **https://www.conference-board.org/data/economydatabase/**. This figure uses recent data to update relationships shown in References 10 and 11.

would result if current dietary trajectories were to continue into the future. Next, we discuss the anticipated environmental and health benefits if healthier diets were to be adopted globally. We then examine other aspects of the global food system, which if modified would also reduce agriculture's health and environmental impacts. We end by highlighting recent food-related policy initiatives and their effectiveness in improving diet-related health and environmental outcomes.

HISTORIC DIETARY SHIFTS AND THEIR HEALTH AND ENVIRONMENTAL IMPACTS

Per capita total caloric food demand, measured as the amount of food per person that enters households, has increased since 1961 as populations have become more affluent and urban (9, 10) (**Figure 1**). Increases in caloric demand have been the most rapid in developing regions that have undergone large increases in per capita gross domestic product (GDP) (11; see also **http://www.fao.org/faostat/en/#home**). For instance, per capita caloric demand has increased >50% to 2,540 kcal/day in South Asia and Southeast Asia and >30% to 3030 kcal/day in Latin America since 1961. Per capita caloric demand in Sub-Saharan Africa was fairly constant between 1960 and 1985, as was per capita GDP, but has increased by >20% since 1985 and is now 2,460 kcal/day. In contrast, total caloric demand in countries that were already affluent in 1961 has been comparatively constant. Caloric demand in Europe, for example, increased 13% to 3,200 kcal/day. The United States is an exception to this otherwise global trend, having experienced a 30% increase

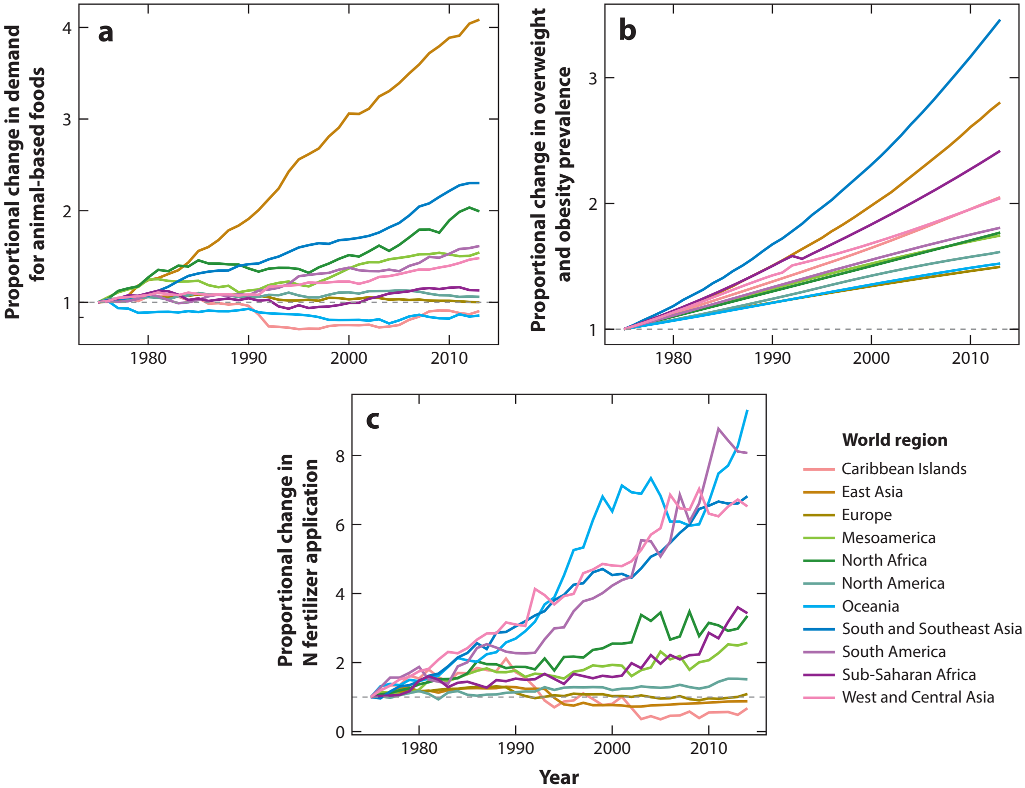

Figure 2

Historical trends in food demand, health, and environmental outcomes for each of 11 geographic regions. Proportional increase, relative to 1975 (which is set at a value of 1.0) in (*a*) daily per capita demand for animal-based foods (meat, fish, dairy, and eggs), (*b*) prevalence of overweight and obesity, and (*c*) application of nitrogenous fertilizers. Data for panels *a* and *c* are from FAOSTAT (**http://www.fao.org/faostat/en/#home**); data for panel *b* are from the World Bank (**http://www.worldbank.org/**).

in caloric demand (800 kcal/day) between 1961 and 2000, although caloric demand in the United States has decreased 70 kcal/day over the past decade to 3,680 kcal/day in 2013 (**Figure 2*a***).

Demand for animal-based foods (meat, fish, dairy, and eggs) has followed similar trends, with the largest increases in consumption in low- and middle-income nations and smaller changes in higher-income nations. Of particular note is the 1300% increase in demand of animal-based foods in China, an increase from 52 kcal/day in 1961 to 724 kcal/day in 2013. Demand for animal-based foods in East Asia increased by 400% to 700 kcal/day, whereas demand in Latin America and the Caribbean increased by 75% to 710 kcal/day. Consumption of animal-based foods is increasing at a slower rate in Sub-Saharan Africa, having increased 17% to 190 kcal/day over the same time period. Consumption trends of animal-based foods in high-income nations vary. For instance, consumption of animal-based foods decreased 15% in Oceania and 5% in North America but increased by more than 20% in Europe. Consumption of animal-based foods in Oceania, North America, and Europe is now 1,000 kcal/day, 970 kcal/day, and 970 kcal/day, respectively.

Demand for sugars and sweeteners has increased rapidly in most world regions (11). Demand in Eastern Asia has increased >150% since 1961 and is now 90 kcal/day, whereas demand in Northern Africa, Sub-Saharan Africa, and South Asia and Southeast Asia has increased >50% to 300 kcal/day, 130 kcal/day, and 210 kcal/day, respectively. Demand for sugars and sweeteners in most other regions has increased between 15% and 40%, although demand in Oceania and Northern Europe has decreased by 24% and 20%, respectively. Current demand for sugars and sweeteners is highest in North America (580 kcal/day), Mesoamerica (450 kcal/day), North Asia (430 kcal/day), and South America (410 kcal/day).

Per capita demand for fresh fruits and vegetables has increased in all world regions except Western Asia. The largest proportional increase in demand for fruits and vegetables was in South Asia and Southeast Asia and in Northern Africa, which experienced a 200% and 150% increase, respectively. Eastern Europe and Northern Europe also had rapid increases in demand for fruits and vegetables. Vegetable demand in Sub-Saharan Africa and Latin America and the Caribbean—regions where the average individual consumes less than one-third the fresh vegetables of any other region—was relatively constant. Current (2013) demand for fresh fruits and vegetables is lowest in Sub-Saharan Africa, Latin America and the Caribbean, and Eastern Europe.

Changes toward diets higher in total calories, animal-based foods, and sugars and sweeteners have been associated with increased prevalence of diet-related diseases such as diabetes, heart disease, and overweight and obesity (**Figure 1*d***). Over the past several decades, diet-related diseases have increased in all world regions but have increased at the fastest rate in regions where dietary shifts and lifestyle changes have been the most rapid.

Diabetes prevalence has increased in all world regions (12). Between 1980 and 2014, the percent of the global adult population suffering from diabetes increased from 4.7% to 8.5% (12, 13). Diabetes prevalence increased most rapidly in those countries that have undergone rapid shifts toward diets higher in sugars and animal-based foods. For instance, diabetes prevalence in China increased from <1% to >10% between 1980 and 2008 as demand for animal-based foods increased by 300% and demand for sugars and other sweeteners increased by 25% (14). Diabetes prevalence has also increased 150% in the Middle East and North Africa (from 5% in 1980 to 12.5% in 2014), 100% in Central Asia (from 5% in 1980 to 10% in 2014), and more than 50% in Southern Africa (from 4% in 1980 to 7% in 2014) and in the Caribbean (from 5% in 1980 to 8% in 2014). Furthermore, the rate of increase of diabetes prevalence has itself been increasing in most of these regions in the past 5–15 years.

The prevalence of overweight and obesity has also increased rapidly. Global prevalence of overweight and obesity increased by 30%—from 29% to 37% of the global adult population—from 1975 to 2014 (15). The increase in overweight and obesity has been especially rapid in developing regions such as South Asia and Southeast Asia (250% increase in prevalence since 1975 to 20% of the adult population being overweight or obese in 2013), East Asia (180% increase to 30% of the adult population), and Sub-Saharan Africa (150% increase to 27% of the adult population). Overweight and obesity prevalence is increasing at a less rapid rate in high-income and developed regions, although the current prevalence of overweight and obesity is higher in these regions than in less affluent and developing regions. For instance, overweight and obesity prevalence increased 50% in Europe and 60% in North America, with 58% of the adult population being overweight or obese in Europe and 66% of the adult population being overweight or obese in North America (**Figure 2*b***).

The recent increase in diet-related diseases has shifted the global burden of disease from diseases associated with infection and underconsumption to those associated with unhealthy diets and overconsumption. In total, diseases associated with unhealthy diets and overconsumption account for 40% of the global burden of disease globally, and often a much higher proportion of the burden of disease in developed countries that have high per capita caloric intakes (16). Furthermore, prevalence of diseases resulting from overconsumption is increasing—even in regions where underconsumption is still widespread (17)—and will likely continue to do so if recent dietary transitions continue (18, 19).

Shifts toward diets higher in calories and animal-based foods have also resulted in increased diet-related environmental impacts. For instance, global nitrogen fertilizer use has increased 860% since 1961 (**Figure 2*c***; see also **http://www.fao.org/faostat/en/#home**). Fertilizer use increased particularly rapidly in developing regions, such as South America (710% increase), South Asia and Southeast Asia (580% increase), and West and Central Asia (570% increase), and slower in the least developed regions such as Sub-Saharan Africa (240% increase) and in more affluent regions such as Europe (8% increase) and North America (50% increase). Runoff from fertilizer application has polluted many large bodies of water (20, 21), and volatilization of nitrogenous fertilizers harms human health via formation of fine particulate matter ($PM_{2.5}$) (6, 7). Atmospheric deposition of agriculturally derived nitrogen also threatens terrestrial ecosystems and their plant diversity (4, 20).

Agricultural land use and GHG emissions have also increased since 1961. The amount of land used for crop production has increased 15% globally, with the largest proportional increases in cropland use occurring in South America (120% increase), Sub-Saharan Africa (65% increase), and Southeast Asia (70%) increase. In contrast, land in crop production decreased in more affluent regions (e.g., North America and Europe). Agricultural GHG emissions have followed a similar trend: proportional increases in GHG emissions have been largest in developing regions such as Sub-Saharan Africa (120% increase), South America (140% increase), and Asia (130% increase), and have changed to a lesser extent in more affluent regions.

Agricultural activities are the leading threat to biodiversity, partially because of agricultural-driven habitat destruction, habitat fragmentation, and fertilizer applications. In total, agricultural activities threaten 70% to 75% of endangered birds and mammals with extinction globally (4), although agriculture threatens a higher percentage of species in regions that have recently undergone rapid industrialization (e.g., South Asia and Southeast Asia, Central America, and South America) and a smaller percentage of species in regions that have not yet been widely industrialized (e.g., Sub-Saharan Africa) (22).

FORECASTS OF FUTURE DIETS

Several analyses have forecasted future dietary patterns by examining historic relationships between per capita consumption and per capita income, urbanization, and several other determinants of dietary patterns (10, 11, 23). These analyses estimate that the global average per capita calorie demand, measured as calories that enter the household, will increase by approximately 11% to 15% from 2005 to 2050 (11, 23). Global demand for animal-based foods is expected to increase more rapidly, with meat demand expected to increase by 26% to 32% and dairy and egg demand expected to increase 20% to 58% by 2050. Shifts toward diets higher in calories and animal-based foods are forecast to be particularly rapid in developing nations, especially those in South Asia, Southeast Asia, and Sub-Saharan Africa, because of the large expected proportional increases in per capita GDP in these regions. In contrast, dietary shifts are expected to be smaller in currently developed nations.

The combination of forecasts of growth in per capita food demand and in global population suggest that global crop production may increase by 60% to 100% from 2005 to 2050 (10, 23, 24). These estimates vary because of different assumptions about the growth of per capita meat demand and the extent to which pasturelands or grains would be used to produce dairy and ruminant meats. Alexandratos & Bruisma (23), who forecast a 60% increase in global crop production, based their estimates on historic trends in national crop production and expert opinion and assume smaller increases in meat consumption and larger amounts of dairy and meat produced on pasturelands. Tilman et al. (10), in contrast, forecast an approximately 100% increase in global crop production by combining UN forecasts of 2050 populations for each country with historic global relationships between per capita wealth and per capita crop demand, which includes both the animal feeds and human foods required to meet per capita food demand. Pardey et al. (24) forecasted that global crop production would increase by 69% from 2010 to 2050 by accounting for population age structure, shifts in consumption between different plant-based foods (e.g., grains to fresh produce), from plant-based foods to animal-based foods, and income-dependent increases in food demand.

ENVIRONMENTAL AND HEALTH IMPACT OF DIFFERENT FOODS

Environment

Recent meta-analyses (11, 25–28) of crop and food life-cycle assessments (LCA) have elucidated the overarching patterns of environmental impacts of producing approximately 100 different foods across multiple environmental indicators. In this section, we review the results of these meta-analyses, discussing how GHG emissions, land use, and nutrient pollution vary among food types (**Figure 3*a***). We compare foods mainly on the basis of their caloric content; however, comparisons of vegetables and fruits are best made in terms of servings because they are primarily consumed for micronutrients rather than their caloric content.

LCA meta-analyses have found that plant-based foods often have the lowest GHG emissions per kilocalorie of food produced. Dairy, eggs, pork, poultry, and low-impact fish production systems (nontrawling fisheries as well as pond, net pen, and flow-through aquaculture systems) have GHG emissions approximately 100% to 2,500% higher than those of plant-based foods per kilocalorie of food produced; and production of high-impact fish (bottom trawling fisheries and recirculating aquaculture) and ruminant meats (beef, sheep, goat) has GHG emissions approximately 2,000% to 10,000% larger than those of plant-based foods per kilocalorie of food produced. The GHG emissions of fish production systems vary because of their energy inputs. Wild-caught fish captured with lines, purse nets, and seine nets can have low energy inputs and relatively low GHG emissions as do unfed, pond, and net pen aquaculture systems. Trawling fisheries (where nets are dragged across the seabed) and recirculating aquaculture (where water is consistently cycled and filtered) emit approximately 200% to 400% more GHGs than other fishery and aquaculture production methods because of their higher energy inputs (11, 25, 26).

The total land required to produce a kilocalorie of food follows a similar trend as GHG emissions. Plant-based foods have the lowest land use requirements per kilocalorie of food produced; dairy and eggs require several times more land than plant-based foods; pork and poultry require approximately 100% to 400% more land than dairy and eggs; and ruminant meats require approximately 2,000% to 10,000% more land (depending on the extent of grazing) than plant-based foods. Production of ruminant meats requires more land than other food, in part because of the inefficiency with which they convert feed into human-edible food. It is unclear how much land is required to produce a unit of fish in aquaculture systems, but it is likely similar to the amount needed for eggs, poultry, or pork because they have similar feed requirements and efficiencies (11).

Nutrient pollution per kilocalorie of food, measured as the amount of nutrients that leave a farming system and enter the surrounding environment, also follows a similar trend. Production of plant-based foods results in the smallest amount of nutrient pollution per kilocalorie of food produced. Production of a kilocalorie of fresh fruits and vegetables results in approximately twice the amount of nutrient pollution as other plant-based foods, which is largely because the caloric contents of vegetables and fruits are low. However, most fruits and vegetables are eaten for their vitamin, mineral, and antioxidant contents rather than for their calories. When measured per serving of food produced, fruits and vegetables have nutrient pollution similar to or lower than

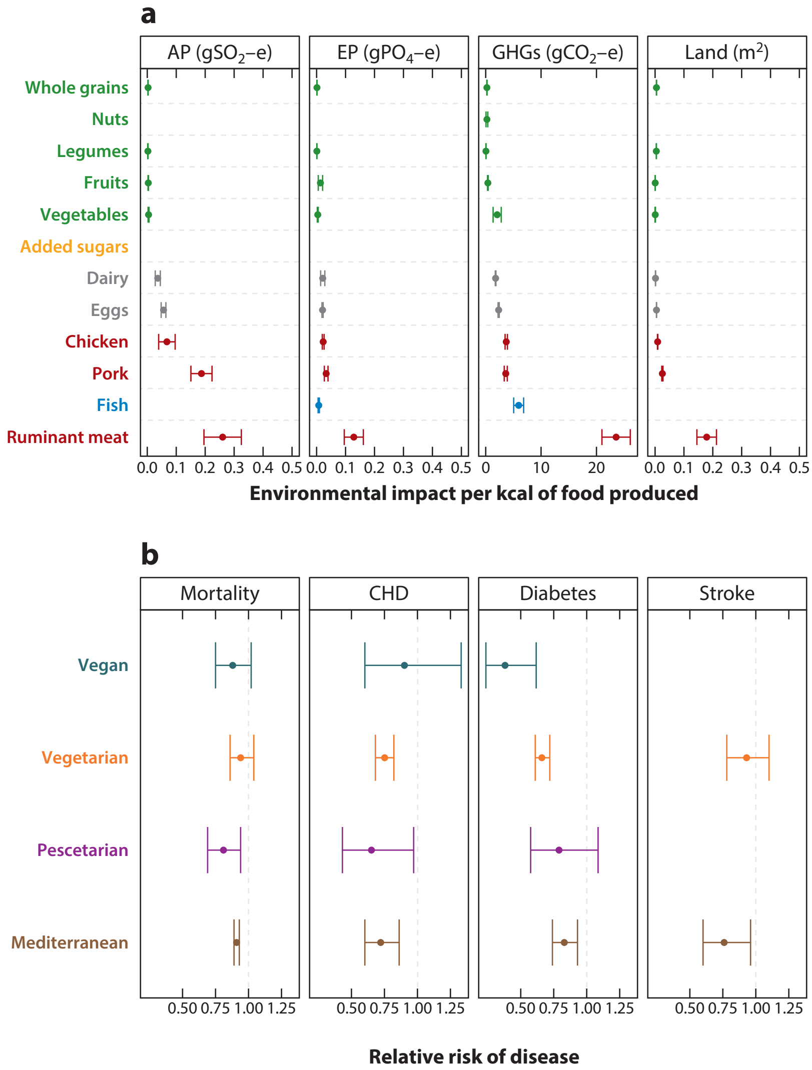

Figure 3

Environmental and health impacts of different foods or dietary patterns. (*a*) Environmental impact per kilocalorie of food produced and (*b*) health outcomes of consuming different diets. In panel *a*, plant-based foods are indicated in green, added sugars are in orange, dairy and eggs are in gray, land-based meats are in red, and fish is indicated in blue. Data for panel *a* are from 26; data for panel *b* are from 57–61. Abbreviations: AP, acidification potential, AP (gSO_2-e), release of pollutants from producing a kcal of food, measured in grams of SO_2; EP, eutrophication potential; g, gram; GHG, greenhouse gas; kcal, kilocalorie.

other plant-based foods. Production of dairy, eggs, poultry, and pork creates intermediate amounts of nutrient pollution, approximately 1,000% to 5,000% higher per unit of food produced than the nutrient pollution from producing plant-based foods. Production of ruminant meat results in the largest amount of nutrient pollution per unit of food, approximately 10,000% higher than production of plant-based foods (26). Aquaculture production in a closed body of water can also contribute to nutrient pollution (29).

Animal-based foods often have higher environmental impacts than plant-based foods because of the inefficiency with which animals convert feed into human-edible food. For nonruminant animals, the environmental impact of animal-based foods is correlated with feed conversion ratio (FCR), or the amount of feed protein required to produce a gram of edible animal protein (11). Eggs and dairy have the lowest impact of animal source foods with FCRs of 2.6 and 3.9, respectively. Poultry and pork have approximately twice the impact of eggs and dairy and have FCRs of 4.9 and 5.7, respectively. Ruminant meats (from cattle, sheep, and goats) have much higher impacts because of their greater FCRs (mutton and goat FCRs are 14.4 and beef FCRs are 19.3) and also because of methane released by their digestive symbionts.

These LCA meta-analyses effectively illustrate the general relative environmental impacts of different foods. However, the majority of LCA publications used in these meta-analyses measured the environmental impacts of production systems that were in North America or Europe and were high input and highly mechanized (25, 26). In addition, because many of the environmental impacts of food production are context dependent and are in part determined by the local ecosystem, it is possible that the environmental impacts of food production in less-westernized, lower-input, and less-mechanized production systems may differ from those discussed here (30, 31).

Food Types, Diets, and Health

A wide variety of methods have been used to study the effects of different diets and foods on human health. In this section, we mainly focus on prospective cohort studies, which examine diets and health outcomes for a cohort of individuals through time. These studies statistically control for age, gender, race, socioeconomic variables, history of smoking, and other variables in determining how different foods or diets may be associated with disease outcomes. By controlling for these factors, and by tracking consumption patterns and disease outcomes through time for large numbers of individuals, researchers are able to estimate the association between consuming an additional serving of food per day and its impact on human health. However, because cohort studies cannot control all potential confounding factors of disease, the association between food consumption and disease incidence may not be causal.

These studies reveal that the health impacts of food consumption are often qualitatively similar to the environmental impact of food consumption. For instance, consuming an additional serving per day of unprocessed plant-based foods is typically beneficial to health (32–37); consuming an additional serving per day of dairy (38, 39), eggs (40, 41), and chicken (42, 43) does not significantly impact health outcomes; and consuming an additional serving per day of red and processed red meats (43–45) contributes to poor health. Although consumption of both red and processed red meats contributes to poor health, consumption of processed red meats is associated with more negative health outcomes than unprocessed red meats, perhaps because of the higher levels of nitrate and nitrite in processed meats (46). The exceptions to the trend are that consuming an additional serving per day of fish (47–49), which often has environmental impacts similar to dairy or chicken, is often beneficial to health, whereas consuming an additional serving per day of sugar (50, 51) or sugar-sweetened beverages (52–54), both of which have relatively low environmental impacts, often contributes to increased disease risk.

Other prospective cohort studies have compared the health outcomes of individuals that have omnivorous dietary patterns to individuals that consume more plant-based diets such as a Mediterranean, pescetarian, vegetarian, or vegan diet. Mediterranean diets are characterized as containing large amounts of fruits, vegetables, whole grains, legumes, moderate amounts of seafood, and small amounts of other meats and as using olive oil as the primary oil. In cohort studies, vegetarian diets contain dairy and eggs, but very limited amounts of other meats;

pescetarian diets include fish, dairy, and eggs, but very limited amounts of other meats; and vegan diets contain very limited amounts of dairy, eggs, or meat.

These dietary analyses have consistently found that diets higher in plant-based foods are associated with reduced disease risk compared to omnivorous dietary patterns (**Figure 3*b***) (11). For instance, shifting from a westernized dietary pattern to one that is more similar to a Mediterranean diet reduces risk of diabetes by 7% (55), and of heart disease by 10% (56), and total mortality by 8% (56). Strict adherence to a Mediterranean diet would likely offer larger health benefits (57). Pescetarian (58, 59), vegetarian (60, 61), and vegan (58, 59, 61) diets also provide health benefits relative to westernized dietary patterns characterized by high consumption of calories, animal products, and sugars and sweeteners.

Although prospective cohort studies are useful in examining the average health impact of different foods, they have some limitations. Most analyses examined food consumption and health outcomes in primarily Caucasian populations; however, health outcomes may differ between ethnicities (62, 63) and genders (63, 64). For instance, diabetes incidence is higher in men than women in Chinese, South Asian, and white populations (63), whereas in the US, cancer rates are higher in African Americans than in Hispanics, Asian Americans, or Caucasians for many types of cancers (62). In addition, analyses that also control for genetic disposition sometimes differ in their results. For example, prospective cohort studies have found that consuming intermediate amounts of alcohol (65) or coffee (66) is associated with a reduced risk of cardiovascular disease, whereas Mendelian analyses that also control for genetic markers have not found a health benefit when consuming any amount of alcohol (67) or coffee (68). Furthermore, the health benefit of consuming an additional serving of food is nonlinear. For example, consuming additional whole-grain cereals when they are already consumed in quantities >100g/day offers smaller health benefits for coronary heart disease and no additional health benefits for stroke or cardiovascular disease (33).

ENVIRONMENTAL AND HEALTH FORECASTS OF DIETARY PATTERNS

Environment

Shifts toward diets higher in calories and animal-based foods, when combined with population growth, are expected to increase global agricultural production by 60%–100% between 2005 and 2050. This large increase in agricultural production is forecast to drive large increases in diet-related environmental impacts such as GHG emissions; land clearing to create croplands and pastures; increased risks of species extinction and biodiversity loss; pollution of freshwaters, aquifers, and marine ecosystems; and $PM_{2.5}$ air pollution from agricultural fertilizers and animal production (**Figure 4*a***).

Agricultural GHG emissions come from four major sources. First, when land is cleared to create new pastures or croplands, the aboveground and root biomass that had been present on that land is commonly burned or decomposes, and the carbon in the biomass is released to the atmosphere as CO_2. The production and use of nitrogen fertilizers is a second major cause of agricultural GHG emissions. Producing nitrogen fertilizer is energy-intensive, releasing large amounts of GHGs. Moreover, a small fraction (often approximately 1%) of applied nitrogen in nitrogen fertilizers is microbially converted into the gas nitrous oxide (N_2O), which is approximately 300 times more potent as a GHG than CO_2 on a per-mass basis. Third, production of rice and ruminants emits methane, a GHG approximately 25 times more potent than CO_2. Fourth, fossil fuel and electricity use on farms release GHG. In total, agricultural GHG emissions currently account for approximately 25% to 33% of total global GHG emissions.

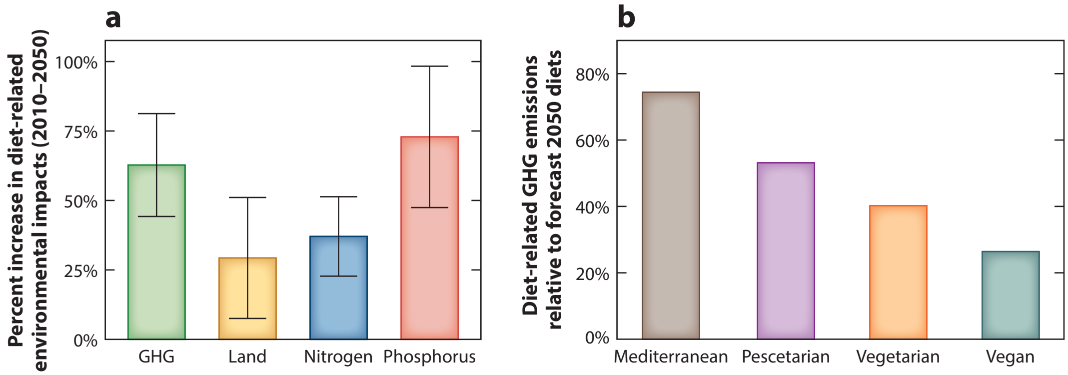

Figure 4

Projected environmental impact of future diets. (*a*) Percent increase in diet-related environmental impacts if current dietary trajectories continue to 2050. (*b*) Greenhouse gas emissions of healthier, more plant-based diets, measured as a percent of GHG emissions from a "business-as-usual" 2050 diet if current dietary trajectories were to continue. Data are from 10, 11, 18, 23, 69–71, 77–79. Abbreviation: GHG, greenhouse gas.

Diet-related GHG emissions are projected to increase approximately 50% to 80% between 2010 and 2050 (11, 18, 69, 70) because of increased consumption of ruminant meats, but also because of land clearing, increased fertilizer application, increased production of rice, and a growing global population. Notably, this projected increase in agricultural GHG emissions is greater than the current global emissions from all forms of transportation combined. Thus, during a period in which vehicle electrification has been proposed as a partial solution to climate change, any climate change benefits it may provide would be substantially less than the increases in agricultural emissions if diets continue to change along current trajectories.

Forecasts of agricultural land expansion to 2050 range from approximately 200 million to 1,000 million hectares because of differing forecasts of future increases in yields and in per capita food demand (10, 11, 22, 23, 70, 71). The estimate that cropland will expand by 200 million hectares assumes that crop yields would grow faster than in the past (along exponential trajectories) and that per capita food demand would increase less than forecasted by other analyses. There is little empirical support for exponential increases in yields; this would be inconsistent with the slowing rate of yield increases observed in most world regions during the past 30 years (72). The estimate that cropland could expand by 1,000 million hectares is based on extrapolating past yield trends and by assuming that per capita crop demand would change along historic income-dependent trajectories. Other analyses forecast intermediate increases in cropland extent to 2050 ranging between 200 and 700 million additional hectares of cropland over the next several decades (11, 22, 70, 71).

Agricultural land expansion increases threats to biodiversity. Threats to biodiversity are forecast to increase the most in developing and tropical nations, where the amount of agricultural land expansion is expected to be greatest (22, 73). Large-bodied animals will be at particular risk from agricultural land expansion because of their large habitat requirements and low population sizes and densities (22). For instance, Visconti et al. (73) estimate that mean species population abundance of large mammals would decline by approximately 18% to 35% by 2050. Tilman et al. (22) forecast that threats to large-bodied mammals and birds will more than double by 2060, equating to a projected average IUCN status of greater than "endangered" for large-bodied mammals and birds in tropical regions. Threats to medium- and small-bodied organisms are also forecast to increase. These analyses, however, may underestimate future extinction risks because they do not account for the negative impact that habitat fragmentation (74, 75) or agricultural intensification (76) may have on biodiversity.

Nitrogen (10, 77–80) and phosphorus (77, 79, 80) fertilizer applications are also forecast to increase as diets shift and populations grow. Global agricultural nitrogen use is forecast to increase by approximately 0 to 190% from 2010 to 2050. The wide range in nitrogen use forecasts is due to differences in underlying assumptions on technological adoption, international trade, and agricultural efficiency (10, 77–80). Phosphorus use is forecast to more than double over the same time period (77, 80). Increased nutrient applications on agricultural land may also increase agricultural runoff, which in turn can lead to poor human health outcomes through polluted water supplies and the formation of marine dead zones where marine aquatic life cannot survive.

The environmental impacts of food consumption are forecast to increase the most in developing nations because of the rapid rate of expected dietary transitions toward more meat-based diets and because of projected high rates of population growth in these nations. In comparison, environmental impacts from food consumption are expected to remain fairly constant in high-income and developed nations because of much lower rates of population growth and smaller expected changes in dietary patterns. However, because food production and consumption do not always occur in the same place, the environmental impacts of agricultural production often occur in a different place than where food is consumed. For instance, agricultural water use in the United States is larger than what would be expected from dietary patterns because the United States exports large amounts of "virtual water" (water used to produce food that is ultimately traded internationally) to other nations (81).

Health

Projected dietary shifts to 2050 are forecast to increase prevalence of diet-related diseases (13, 19). Diabetes prevalence is forecast to increase by 55% globally from 2000 to 2030. The increase in diabetes prevalence is expected to be more rapid in regions currently undergoing large shifts toward diets higher in meats, sugars, and total calories. Indeed, by 2030 diabetes prevalence is forecast to increase by 100% in the Middle East and North Africa, by >70% in South Asia and Southeast Asia, and by 60% in Sub-Saharan Africa (13, 19). More affluent regions such as Europe (22% increase) and North America (37% increase) have smaller forecasted increases in diabetes by 2030 because of smaller dietary and lifestyle changes (13, 19).

Global forecasts of other diet-related diseases show similar trends. From 2005 to 2050, cardiovascular disease mortality is forecast to increase >50% in China (82) and the United States (83). Prevalence of overweight and obesity will also continue to increase if dietary patterns and lifestyles do not change, with the largest increases forecasted for currently developing nations (18). In total, diet-related diseases will account for two-thirds to three-quarters of the total global burden of disease by 2030 if current trajectories continue (84).

DIETARY SHIFTS AS A SOLUTION TO THE DIET-HEALTH-ENVIRONMENT TRILEMMA

Adopting a healthier and more plant-based diet, such as a Mediterranean, vegetarian, pescetarian, or vegan diet, could provide large global environmental benefits relative to current and forecasted future diets (85). Global adoption of these healthier diets could reduce global 2050 diet-related GHG emissions by approximately 30% to 60% (11, 18, 70) (**Figure 4*b***), decrease future cropland use by approximately 20% to 35% (11, 70), reduce future threats to biodiversity (22), and reduce nitrogen (78, 79) and phosphorus (79) fertilizer inputs relative to forecasted future dietary impacts.

The environmental benefits of adopting healthier and more plant-based diets would vary greatly among nations if one were to look solely at the changes in environmental impacts associated with a change to healthier diets. Adopting healthier diets in developed nations would reduce per capita diet-related environmental impacts down to this baseline, largely because of reduced consumption of ruminant meats, other meats, and total calories (11, 18). Other countries that consume large quantities of ruminant meat, such as Argentina and Brazil, would also experience large environmental benefits from healthier diets. Adoption of healthier diets in food-insecure developing nations would increase their per capita diet-related environmental impacts because of increased consumption of total calories and animal products, but would also decrease the prevalence of malnutrition in these nations (18).

Diets with lower environmental impacts are not necessarily healthy, and healthier diets do not necessarily have lower environmental impacts. Adopting the healthy dietary pattern recommended by the US government would increase diet-related GHG emissions in the United States (86). In contrast, a hypothetical diet that met caloric needs and minimized diet-related greenhouse gas emissions reduced GHG emissions by 90% relative to the usual diet of the United Kingdom, but was likely to be unhealthy, containing only seven food items in unrealistic quantities and no fruits or vegetables (87). Substituting foods with in a diet can also improve health but may be associated with either decreased or increased GHG emissions. For instance, an isocaloric substitution of whole grains, nuts, legumes, fish, dairy, or eggs for red meat is associated with improved health (88) and would likely reduce diet-related environmental impacts, whereas an isocaloric substitution of fresh produce for red meat would also improve health outcomes but have a smaller GHG benefit (89).

Shifting toward healthier dietary patterns would improve diet-related health outcomes. Increased adoption of a combination or a mixture of Mediterranean, pescetarian, vegetarian, or vegan diets would reduce the risk of diabetes, cancer, heart disease, overweight and obesity, and total mortality relative to expected dietary patterns in 2050 (18). In total, adoption of a more plant-based diet would reduce mortality from coronary heart disease, stroke, cancer, and type 2 diabetes by 12% to 19% and total global mortality by 6% to 10% (5.1 to 8.1 million fewer deaths per year) by 2050, and provide major environmental benefits. The health benefits of such diets are primarily from reduced consumption of red meat and decreased prevalence of overweight and obesity, but also because of increased intake of nuts, fruits, and vegetables (18). Epidemiological studies examining dietary patterns and health outcomes also show that adoption of plant-based diets would improve health outcomes in affluent regions that consume large quantities of animal-based foods (e.g., 59, 90), although increased consumption of animal-based foods in undernourished populations might improve health outcomes (91).

OTHER ROUTES TO IMPROVED AGRICULTURAL SUSTAINABILITY

There are many ways other than adopting more plant-based diets to improve agricultural sustainability. The next section highlights several inefficiencies in the current agricultural system that, if overcome, could greatly increase agricultural sustainability.

Closing Yield Gaps

Crop yields in many developing nations could be greatly increased by greater access to agricultural inputs and by using agricultural inputs more efficiently (92; see also **http://www.yieldgap.org/water-productivity**). For instance, 94 nations have average crop yields that are less than half of their potential, whereas 43 nations have yields less than one-third of their potential (**Figure 5**).

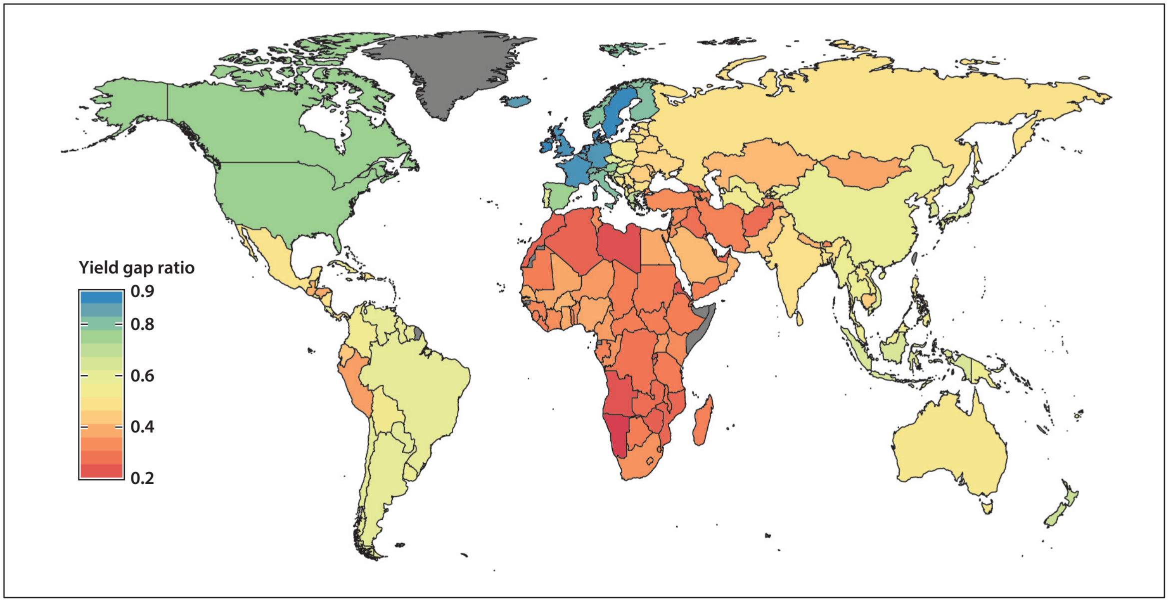

Figure 5

Existing crop yield gaps. Shown is the ratio of current yields to potential yields, as estimated by 92 (see also **http://www.yieldgap.org/water-productivity**). A ratio of 0.2 indicates that a nation, on average, has crop yields 20% of what that nation is capable of yielding. Low ratios indicate large yield gaps, or the difference between current yields and potential yields. Countries in gray are missing data on either current yields or potential yields.

Nearly half of these nations are in Sub-Saharan Africa; others are in South Asia, Southeast Asia, and Latin America. Increasing crop yields by decreasing the difference between current and potential yields, an idea known as closing yield gaps, would simultaneously improve environmental outcomes (10, 11, 22, 70), increase farmer income, and improve food security and diet-related health outcomes (93, 94). For instance, global food production would increase 28% or 58% if every nation were to achieve crop yields equivalent to 75% or 95% of their potential crop yields, respectively (94). Smaller closures in yield gaps would also have globally significant ramifications; increasing crop yields to 50% of their potential yields in low-performing areas would increase crop production enough to feed an additional 850 million people per year (95).

Closing yield gaps is possible with existing technologies and management techniques. Planting and intercropping agricultural fields with grains and legumes (96); using cover crops and manure to increase soil fertility; increasing access to improved seeds, fertilizers, and pesticides; and better timing fertilizer application with crop nutrient demand are effective methods for increasing crop yields (97). National government programs in Malawi (98), Rwanda, Zambia, Ghana, Mali, and Senegal (99) that increased access to agricultural inputs successfully increased crop yields by 20–80%. Smaller-scale interventions such as integrated pest management (100) and use of nitrogen-fixing crops during fallow periods, among other methods (101, 102), have also increased crop yields in low-yielding regions.

Closing yield gaps is not without potential environmental or economic drawbacks. Increasing crop yields by closing yield gaps often requires increased nutrient inputs such as water and fertilizer (92). Increasing water use in arid and drought-stricken regions could stress water resources, and it may not be possible if irrigation water is in short supply. Increasing fertilizer application could also lead to increased nutrient runoff if management techniques designed to limit nutrient runoff, especially efficient methods of fertilization, are not also adopted when fertilizer inputs are increased. In addition, maintaining yields at levels greater than 75% to 85% of maximum potential yields may not be more economically profitable, depending on crop and fertilizer prices, than maintaining yields at slightly lower levels (103).

Reducing Food Waste

Thirty to forty percent of global food production is ultimately lost or wasted (104). Lower-income and developing nations waste a larger proportion of food during production and transport, largely because of lack of infrastructure and poor storage facilities. In contrast, higher-income nations tend to waste more food at retail stores and households, partially because of aesthetic quality standards. Solutions designed to reduce food loss and waste will as such need to account for local contexts and the underlying causes of food loss and waste.

Reducing food loss and waste could improve environmental outcomes and increase food security. For instance, cutting food loss and waste in half would reduce global irrigation water use by 11%, land use by 9%, and fertilizer use by 10% (105). In addition, halving food loss and waste would also potentially increase food availability by 1,300 trillion kcal per year by 2050, or 22% of the estimated crop production increase required to meet estimated crop production in 2050 (106).

Reducing food waste is possible at all points in the food supply chain. Intermarché, a French supermarket, reduced food waste and increased their profits by selling misshapen produce at a discount (see **http://itm.marcelww.com/inglorious**). Other supermarkets have since adopted similar programs. National governments, such as those in France and Italy, have laws that encourage or require grocery stores to donate food that would otherwise be wasted. Increasing access to refrigeration, storage technologies and facilities, and market access, as well as improving crop production and harvest techniques, could reduce food loss and waste in low-income nations (104).

Increasing Efficiency of Fertilizer Applications

Increasing fertilizer use efficiency, or the amount of food produced per unit of fertilizer input, would reduce nutrient runoff and emissions of pollutants that contribute to climate change and reduced air quality (107, 108). Low fertilizer use efficiency results from over application of fertilizer and temporal and spatial mismatch between fertilizer application and crop nutrient demand. Mismatches between fertilizer application and crop nutrient demand ultimately result in fertilizer leaching into ground waters (e.g., aquifers), flowing into surface waters (e.g., rivers), and, for nitrogen, being emitted as nitrous oxide that causes climate change or as ammonia that creates $PM_{2.5}$. Fertilizer runoff can create dead zones, cause biodiversity loss, and also contribute to poor health outcomes by increasing nitrate and nitrite levels in drinking water (109) and contributing to air pollution (6, 7).

Improving fertilizer use efficiency is possible with existing technologies and management strategies. Precision agriculture, a management technique that improves the match between crop nutrient demand and nutrient application, has reduced fertilizer runoff in a variety of crops (107). Incorporating cover crops into crop rotations can also reduce nutrient runoff, and using nitrogen-fixing crops as cover crops would simultaneously reduce the need for nitrogen fertilizer inputs. Creating buffer strips at edges of pastures (110) and croplands (111, 112) can decrease fertilizer runoff by >90% and herbicide runoff by >60% while also providing ecosystem services such as carbon sequestration (111) and habitat for pollinators (112).

Governmental policy interventions have been effective at improving fertilizer use efficiency and reducing fertilizer runoff. The EU Nitrates Directive, established in 1991, aimed to decrease fertilizer runoff because of its effect on human health (113). Since the Nitrates Directive was established, N fertilizer application decreased 30% and P and K applications decreased 70% without negatively affecting the rate at which national crop yields (measured as national mean kilocalories per hectare) increased. In addition, water quality and human health outcomes associated with excess nutrient runoff have improved in the EU (114). Analyses conducted in other developed nations have also shown that national-average fertilizer application rates could be decreased by 25% without negatively impacting crop yields (108).

Land Use Planning

Conservation-based land use planning could reduce agriculture's future environmental impacts. Establishing new protected areas (e.g., national parks, conservation reserves, etc.) to meet and/or exceed the Aichi Biodiversity Targets (see **https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0683&from=en**) would improve biodiversity outcomes (115). This is particularly true if protected areas were larger or linked together to allow for migration between neighboring protected areas or to decrease habitat fragmentation in regions at risk of land clearing (116). Increasing enforcement of existing protected areas to reduce hunting, poaching, and resource extraction would improve biodiversity outcomes, but could also increase food insecurity in regions that rely on the nutrition provided by bushmeat (117).

Leveraging national, regional, and global food trade patterns to avoid increased production in biologically sensitive or low-yielding regions could also improve global environmental outcomes. For example, a recent analysis showed that preferentially growing crops in countries with high yields for export to countries with low yields could prevent approximately 25 to 75% of the expected increase in future threats to biodiversity (22). Such trade-based conservation measures, however, would be constrained by local food preferences and should ensure adequate food sovereignty and security. Analyses conducted at smaller spatial scales have also shown that land use planning can improve biodiversity outcomes while simultaneously increasing economic output (118). However, while trade-based measures would decrease environmental impacts over large spatial scales (e.g., globally), they would simultaneously increase environmental impacts in the regions to which agricultural production is shifted. For instance, shifting agricultural production from lower- to higher-yielding regions would decrease total land in agricultural production, but would also increase the amount of land in agricultural production in higher-yielding regions (22).

Integrated Agriculture

There are environmental trade-offs between organic (as it is called in the United States; ecological in Europe) and conventional agricultural systems. On average across all crops, per unit of food produced, organic agricultural systems require more land (26, 119, 120) and have higher rates of nutrient runoff. Conventional systems require more energy (26, 120), have lower soil organic carbon stocks (121), and have decreased biodiversity (122–124) relative to organic systems. Organic foods also have lower pesticide residues (125) and higher micronutrient concentrations (126, 127), although these differences may not provide observable health benefits (126, 128). However, some organic crops, especially short-statured fruits and vegetables, have been associated with outbreaks of *E. coli* and other pathogens when unsterilized manure was a nitrogen source (129).

Integrating the benefits of different systems of food production, for instance the higher yields of conventional systems, higher soil organic carbon stocks of organic systems, and reduced reliance on synthetic inputs in organic systems and systems with higher crop diversity (96, 130), might create a more sustainable integrated agricultural system than what currently exists. Moreover, because the environmental and health impacts and productivity of agriculture are context dependent (30, 31), the most sustainable and productive systems will vary depending on local environmental, cultural, and political systems. Developing an integrated agricultural system that combines the benefits of organic and conventional systems could lead to a more sustainable agricultural future.

PATHWAYS TO HEALTHIER AND MORE SUSTAINABLE DIETS

Finding ways to increase adoption of healthier and more sustainable diets may be difficult. Humans evolved to prefer foods high in fats, protein, sugar, and salt (131)—which are now often found in large quantities in those commercially processed foods that are also often associated with poor health or large environmental impacts. Meat consumption is also a sign of affluence and wealth in many cultures (132), whereas multinational corporations focus on maximizing profits by marketing palatable and cheap foods that are also often unhealthy (133). Recent policy interventions in culturally, socially, economically, and politically diverse nations may provide insight into future policies that could be effective at improving diet-related health and environmental outcomes if more widely adopted.

Changing the food environment could be effective at changing dietary patterns. Increasing access to healthier foods (e.g., fruits and vegetables) while decreasing access to less healthy foods has been found to increase consumption of fresh fruits and vegetables and decrease consumption of processed foods at households, schools, and work places (134). Dish and package size are positively correlated with per capita caloric intake, and reducing dish and package size may help reduce caloric intake. For instance, when serving size doubles, caloric intake increases 18% to 25% for meal-related foods (e.g., pasta) and 30% to 45% for snacks (135). Sharing meals can also alter food consumption patterns. Individuals consume 33% more when sharing meals with one other person and 45% more when sharing meals with two others (136, 137), but sharing frequent family meals increases consumption of fresh produce and decreases consumption of soft drinks (138). Changing the food environment in these, and other, ways could likely help shift caloric consumption and dietary patterns in healthier ways.

Taxation of less healthy or less sustainable foods has also been effective at shifting dietary patterns. Taxes on sugar-sweetened beverages such as sodas and sweetened fruit juices in Mexico (139) and several cities in the United States (140) have decreased consumption of taxed beverages by up to 10%. A Danish tax on foods high in saturated fats (e.g., butter and margarine) also decreased consumption of taxed foods (141). Taxes on unhealthy foods are not universally effective, nor may they be long lasting, possibly because such taxes are regressive and may not be an ideal solution to shifting diets. For instance, a tax on sugar-sweetened beverages in Chicago (142) was repealed after two months, whereas the Danish tax on foods high in saturated fats (143) was repealed after two years because of consumer and political opposition.

Food labeling can be, but is not always, effective at shifting dietary habits. Back-of-package nutrition labeling increases consumption of healthier foods and decreases caloric consumption among label users (144). Labeling foods with "traffic light labels" (where "good" foods are labeled with green and "bad" foods labeled with red) for health (145, 146) or environmental (147) purposes has been associated with increased purchases of healthy or sustainable foods and decreased purchases of less healthy and less sustainable foods. Labeling appears to be more effective among individuals who are concerned about health or environmental outcomes (145), but the potential benefits of labeling may be negated when healthy or sustainable foods are more expensive than alternatives (147). Calorie labeling at fast food restaurants in the United States was enacted to reduce the number of calories purchased, although this has not been associated with a change in the number of calories purchased at fast food outlets (148).

It seems plausible, but is as yet unclear, that integrating sustainability into government-recommended dietary guidelines could increase rates of adoption of healthier diets and could be effective at reducing diet-related environmental impacts. Brazil, Germany, Sweden, and Qatar have incorporated environmental sustainability into their government dietary guidelines, and the Netherlands and the United Kingdom are beginning to do so (149).

CONCLUSIONS

The diet-health-environment trilemma is created by the dietary choices people commonly make as incomes and urbanization increase, combined with the negative impacts of these diets on health and the environment. These negative impacts will grow greatly in the next several decades if current diet trajectories continue. For instance, by 2050, diet-related GHG emissions are forecast to increase 50% to 80% (11, 18) and land use by 200 to 1,000 (10, 23) million hectares, while also increasing threats to biodiversity (22, 73) and harming ecosystems and human health from excess nitrogen and phosphorus fertilizer applications and runoff (77, 78, 97). These dietary shifts would simultaneously increase the prevalence of diet-related diseases such as overweight and obesity, diabetes, and heart disease (18), ultimately leading to diet-related diseases being three-quarters of the global burden of disease by 2030 (84). Global adoption of healthy plant-based diets could prevent much of the expected increase in diet-related environmental impacts and also reduce expected diet-related mortality by 12% to 19% by 2050 (18). Improving other aspects of the global agricultural system, such as increasing crop yields in underyielding areas (11, 22), reducing food waste (105), improving fertilizer use efficiency (107, 108), and creating an integrated agricultural system that combines the benefits of organic and conventional agricultural systems (26), would further improve agricultural sustainability and food security.

Solving the diet-health-environment trilemma will not be easy. Policies designed to decrease consumption of less healthy and less sustainable foods and instead increase adoption of healthier and more sustainable foods could improve the health and environmental outcomes of dietary patterns. Existing policies such as taxing (139, 141) or labeling (145, 146) unhealthy or unsustainable foods may offer more benefits if adopted more widely (150). However, policies also need to account for the cultural, economic, social, and political environment to be effective, and it is possible that a policy that is effective in one region may be ineffective in another (e.g., 139, 142). One of the great challenges of our era is finding ways to widely achieve adoption of diets that improve health and environmental outcomes.

SUMMARY POINTS

1. The diet-health-environment trilemma results from the dietary choices individuals make and their effects on health and the environment.
2. Historical shifts toward diets higher in calories and animal-based foods as populations have become more affluent have resulted in increased diet-related environmental impacts and the prevalence of diet-related diseases such as diabetes, heart disease, and overweight and obesity.
3. Continued dietary shifts toward diets higher in calories and animal-based foods are expected to result in increases in prevalence of diet-related diseases and a 50% to 80% increase in diet-related greenhouse gas emissions, as well as other negative environmental impacts.
4. Adoption of healthier and more plant-based dietary patterns would simultaneously improve health outcomes and diet-related environmental impacts relative to expected dietary patterns. For instance, global adoption of a vegetarian diet would reduce diet-related

mortality by 17% relative to forecast dietary patterns, and it would reduce diet-related environmental impacts by 60%.

5. Addressing other inefficiencies in the global agricultural system using current technologies and management techniques could also reduce agriculture's environmental impact. Reducing food waste by half would decrease agriculture's irrigation water use by 11%, land use by 9%, and fertilizer use by 10%. Increasing crop yields in underyielding nations could also prevent the expansion of cropland while also increasing crop production enough to feed an additional 850 million people per year.
6. The diet-health-environment trilemma is one of the key issues facing global societies. Finding solutions that shift diets toward healthier and more sustainable dietary patterns would have globally significant health and environmental benefits. Taxation and food labeling have often been, but are not always, effective at shifting diets in healthier and more sustainable directions. Further research into the policies and interventions that are most effective at shifting diets toward healthier and more sustainable dietary patterns is needed.

FUTURE ISSUES

1. How will climate change affect the diet-health-environment trilemma? Will it amplify or mediate the links between diet, health, and environment?
2. To what extent does air pollution from agriculture impact human health? What are the economic damages of these health impacts, and how can they be reduced?
3. What are the expected spatial patterns of agriculturally driven threats to biodiversity, and how can conservation actions be targeted at these spatial scales?
4. Which policies, government programs, corporate marketing campaigns, and other interventions are effective, and which are not, at shifting diets toward healthier and more sustainable dietary patterns?

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

We thank the International Balzan Prize Foundation, the McKnight Presidential Chair, the Long Term Ecological Research program of the US National Science Foundation, the University of Minnesota, the University of California, Santa Barbara, the US Environmental Protection Agency (R835873), and the US Department of Agriculture (MIN-12-083) for support.

LITERATURE CITED

1. FAO, IFAD, UNICEF, WFP, WHO. 2017. *The State of Food Security and Nutrition in the World 2017*. Rome: FAO
2. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, et al. 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 6736(14):1–16

3. Intergovernmental Panel on Climate (IPCC) Core Writing Team, Pachauri PK, Meyer LA, eds. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC
4. International Union for Conservation of Nature (IUCN). 2017. *The IUCN Red List of Threatened Species*, Version 2016–5. Red List Threat. Spec., IUCN. **http://www.iucnredlist.org**
5. Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. 1997. Human domination of Earth's ecosystems. *Science* 277:494–99
6. Bauer SE, Tsigaridis K, Miller R. 2016. Significant atmospheric aerosol pollution caused by world food cultivation. *Geophys. Res. Lett.* 43:5394–400
7. Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* 525(7569):367–71
8. Molden D, ed. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London: Earthscan; Colombo, Sri Lanka: Int. Water Manag. Inst.
9. Kearney J. 2010. Food consumption trends and drivers. *Philos. Trans. R. Soc. Lond. B* 365:2791–807
10. Tilman D, Balzer C, Hill J, Befort BL. 2011. Global food demand and the sustainable intensification of agriculture. *PNAS* 108(50):20260–64
11. Tilman D, Clark M. 2014. Global diets link environmental sustainability and human health. *Nature* 515(7528):518–22
12. Ezetti M, Lu Y, Bentham J, Danaei G, Bixby H, et al. 2016. Worldwide trends in diabetes since 1980: a pooled analysis of 751 population-based studies with 4.4 million participants. *Lancet* 387(10027):1513–30
13. World Health Organization (WHO). 2016. *Global Report on Diabetes*. Geneva: WHO
14. Hu FB. 2011. Globalization of diabetes: the role of diet, lifestyle, and genes. *Diabetes Care* 34:1249–57
15. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, et al. 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 384(9945):766–81
16. Forouzanfar M, Alexander L, Anderson HR, Bachman V, Biryukov S, et al. 2015. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 386:2287–1323
17. Abdullah A. 2015. The double burden of undernutrition and overnutrition in developing countries: an update. *Curr. Obes. Rep.* 4(3):337–49
18. Springmann M, Godfray HCJ, Rayner M, Scarborough P. 2016. Analysis and valuation of the health and climate change cobenefits of dietary change. *PNAS* 113(15):4146–51
19. Euromonitor International. 2017. Global diabetes prevalence in 2000 versus 2030 forecast. *Euromonitor International*, Nov. 8. **https://blog.euromonitor.com/2017/11/interactive-map-global-diabetes-prevalence-2000-vs-2030-forecast.html**
20. Vitousek PM, Aber JD, Howarth RW, Likens GE, Matson PA, et al. 1997. Human alteration of the global nitrogen cycle: sources and consequences. *Ecol. Appl.* 7(3):737–50
21. Smith VH, Tilman GD, Nekola JC. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environ. Pollut.* 100:179–96
22. Tilman D, Clark M, Williams D, Kimmel K, Polasky S, et al. 2017. Future threats to biodiversity and pathways to their prevention. *Nature* 546:73–81
23. Alexandratos N, Bruinsma J. 2012. *World agriculture towards 2030/2050: the 2012 revision*. ESA Work. Pap. 12-03, Agric. Dev. Econ. Div., Food Agric. Organ. UN Rome
24. Pardey PG, Beddow JM, Hurley TM, Beatty TKM, Eidman VR. 2014. A bounds analysis of world food futures: global agriculture through to 2050. *Aust. J. Agric. Resour. Econ.* 58(4):571–89
25. Clune S, Crossin E, Verghese K. 2017. Systematic review of greenhouse gas emissions for different fresh food categories. *J. Clean. Prod.* 140:766–83
26. Clark M, Tilman D. 2017. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environ. Res. Lett.* 12:064016
27. Nijdam D, Rood T, Westhoek H. 2012. The price of protein: review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy* 37(6):760–70

28. de Vries M, de Boer IJM. 2010. Comparing environmental impacts for livestock products: a review of life cycle assessments. *Livest. Sci.* 128:1–11
29. Food and Agricultural Organization of the United Nations (FAO). 2016. *The State of World Fisheries and Aquaculture: Contributing to Food Security and Nutrition for All*. Rome: FAO
30. Herrero M, Havlík P, Valin H, Notenbaert A, Rufino MC, et al. 2013. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *PNAS* 110(52):20888–93
31. Carlson KM, Gerber JS, Mueller ND, Herrero M, MacDonald GK, et al. 2016. Greenhouse gas emissions intensity of global croplands. *Nat. Clim. Change* 7:63–68
32. Aune D, Giovannucci E, Boffetta P, Lars T, Keum N, et al. 2017. Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality—a systematic review and dose-response meta-analysis of prospective studies. *Int. J. Epidemiol.* 46:1029–56
33. Aune D, Keum N, Giovannucci E, Fadnes LT, Boffetta P, et al. 2016. Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: systematic review and dose-response meta-analysis of prospective studies. *Br. Med. J.* 353:i2716
34. Grosso G, Yang J, Marventano S, Micek A, Galvano F, Kales SN. 2015. Nut consumption on all-cause, cardiovascular, and cancer mortality risk: a systematic review and meta-analysis of epidemiologic studies. *Am. J. Clin. Nutr.* 101:783–93
35. Aune D, Norat T, Romundstad P, Vatten LJ. 2013. Whole grain and refined grain consumption and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis of cohort studies. *Eur. J. Epidemiol.* 28(11):845–58
36. Afshin A, Micha R, Khatibzadeh S, Mozaffarian D. 2014. Consumption of nuts and legumes and risk of incident ischemic heart disease, stroke, and diabetes: a systematic review and meta-analysis. *Am. J. Clin. Nutr.* 100:278–89
37. Wu Y, Zhang D, Jiang X, Jiang W. 2015. Fruit and vegetable consumption and risk of type 2 diabetes mellitus: a dose-response meta-analysis of prospective cohort studies. *Nutr. Metab. Cardiovasc. Dis.* 25:140–47
38. Mullie P, Pizot C, Autier P. 2016. Daily milk consumption and all-cause mortality, coronary heart disease and stroke: a systematic review and meta-analysis of observational cohort studies. *BMC Public Health* 16:12361
39. Aune D, Norat T, Romundstad P, Vatten LJ. 2013. Dairy products and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis of cohort studies. *Am. J. Clin. Nutr.* 98(4):1066–83
40. Rong Y, Chen L, Zhu T, Yu M, Shan Z, et al. 2013. Egg consumption and risk of coronary heart disease and stroke: dose-response meta-analysis of prospective cohort studies. *BMJ* 346(8539):e8539
41. Wallin A, Forouhi NG, Wolk A, Larsson SC. 2016. Egg consumption and risk of type 2 diabetes: a prospective study and dose-response meta-analysis. *Diabetologia* 59:1204–13
42. Abete I, Romaguera D, Vieira AR, Lopez de Munain A, Norat T. 2014. Association between total, processed, red and white meat consumption and all-cause, CVD and IHD mortality: a meta-analysis of cohort studies. *Br. J. Nutr.* 112(5):762–75
43. Feskens EJM, Sluik D, van Woudenbergh GJ. 2013. Meat consumption, diabetes, and its complications. *Curr. Diab. Rep.* 13:298–306
44. Wang X, Lin X, Ouyang YY, Liu J, Zhao G, et al. 2015. Red and processed meat consumption and mortality: dose-response meta-analysis of prospective cohort studies. *Public Health Nutr.* 19(5):893–905
45. Chen G, Lv D, Pang Z, Liu Q. 2013. Red and processed meat consumption and risk of stroke: a meta-analysis of prospective cohort studies. *Eur. J. Clin. Nutr.* 67:91–95
46. Etemadi A, Sinha R, Ward MH, Graubard BI, Inoue-Choi M, et al. 2017. Mortality from different causes associated with meat, heme iron, nitrates, and nitrites in the NIH-AARP Diet and Health Study: population based cohort study. *BMJ* 357:j1957
47. Zhao L, Sun J, Yang Y, Ma X, Wang Y, Xiang Y. 2015. Fish consumption and all-cause mortality: a meta-analysis of cohort studies. *Eur. J. Clin. Nutr.* 70:155–61
48. Daley CA, Abbott A, Doyle PS, Nader GA, Larson S. 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutr. J.* 9:10

49. Zheng J, Huang T, Yu Y, Hu X, Yang B, Li D. 2012. Fish consumption and CHD mortality: an updated meta-analysis of seventeen cohort studies. *Public Health Nutr*. 15(4):725–37
50. Tasevska N, Park Y, Jiao L, Hollenbeck A, Subar AF, Potischman N. 2014. Sugars and risk of mortality in the NIH-AARP Diet and Health Study. *Am. J. Clin. Nutr.* 99:1077–88
51. Yang Q, Zhang Z, Gregg EW, Flanders WD, Merritt R, Hu FB. 2014. Added sugar intake and cardiovascular diseases mortality among US adults. *JAMA Intern. Med.* 174(4):516–24
52. Huang C, Huang J, Tian Y, Yang X, Gu D. 2014. Sugar sweetened beverages consumption and risk of coronary heart disease: a meta-analysis of prospective studies. *Atherosclerosis* 234(1):11–16
53. Imamura F, O'Connor L, Ye Z, Mursu J, Hayashino Y, et al. 2015. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. *BMJ* 351:h3576
54. Xi B, Huang Y, Reilly KH, Li S, Zheng R, et al. 2015. Sugar-sweetened beverages and risk of hypertension and CVD: a dose-response meta-analysis. *Br. J. Nutr.* 113:709–17
55. Schwingshackl L, Missbach B, König J, Hoffmann G. 2015. Adherence to a Mediterranean diet and risk of diabetes: a systematic review and meta-analysis. *Public Health Nutr*. 18(7):1292–99
56. Sofi F, Macchi C, Abbate R, Gensini GF, Casini A. 2013. Mediterranean diet and health status: an updated meta-analysis and a proposal for a literature-based adherence score. *Public Health Nutr*. 17(12):2769–82
57. Dinu M, Pagliai G, Casini A, Sofi F. 2018. Mediterranean diet and multiple health outcomes: an umbrella review of meta-analyses of observational studies and randomised trials. *Eur. J. Clin. Nutr.* 72:30–43
58. Tonstad S, Stewart K, Oda K, Batech M, Herring RP, Fraser GE. 2013. Vegetarian diets and incidence of diabetes in the Adventist Health Study-2. *Nutr. Metab. Cardiovasc. Dis.* 23(4):292–99
59. Orlich MJ, Singh PN, Sabaté J, Jaceldo-Siegl K, Fan J, et al. 2013. Vegetarian dietary patterns and mortality in Adventist Health Study 2. *JAMA Intern. Med.* 173(13):1230–38
60. Satija A, Bhupathiraju SN, Rimm EB, Spiegelman D, Chiuve SE, et al. 2016. Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies. *PLOS Med*. 13(6):e1002039
61. Dinu M, Abbate R, Gensini GF, Casini A, Sofi F. 2017. Vegetarian, vegan diets and multiple health outcomes: a systematic review with meta-analysis of observational studies. *Crit. Rev. Food Sci. Nutr.* 57(17):3640–49
62. Siegel RL, Miller KD, Jemal A. 2017. Cancer Statistics, 2017. *CA: Cancer J. Clin.* 67(1):7–30
63. Khan NA, Wang H, Anand S, Jin Y, Campbell NRC, et al. 2011. Ethnicity and sex affect diabetes incidence and outcomes. *Diabetes Care* 34:96–101
64. Mosca L, Benjamin EJ, Berra K, Bezanson JL, Dolor RJ, et al. 2011. Effectiveness-based guidelines for the prevention of cardiovascular disease in women—2011 update: a guideline from the American Heart Association. *Circulation* 123:1242–62
65. Ronksley PE, Brien SE, Turner BJ, Mukamal KJ, Ghali WA. 2011. Association of alcohol consumption with selected cardiovascular disease outcomes: a systematic review and meta-analysis. *BMJ* 342:d671
66. Ding M, Bhupathiraju SN, Chen M, van Dam RM, Hu FB. 2014. Caffeinated and decaffeinated coffee consumption and risk of type 2 diabetes: a systematic review and a dose-response meta-analysis. *Diabetes Care* 37(February):569–86
67. Holmes MV, Dale CE, Zuccolo L, Silverwood RJ, Guo Y, et al. 2014. Association between alcohol and cardiovascular disease: Mendelian randomisation analysis based on individual participant data. *BMJ* 349:g4164
68. Nordestgaard AT, Nordestgaard BG. 2016. Coffee intake, cardiovascular disease and all-cause mortality: observational and Mendelian individuals. *Int. J. Epidemiol.* 45(6):1938–52
69. Popp A, Lotze-campen H, Bodirsky B. 2010. Food consumption, diet shifts and associated non-CO_2 greenhouse gases from agricultural production. *Glob. Environ. Change* 20(3):451–62
70. Bajzelj B, Richards KS, Allwood JM, Smith P, Dennis JS, et al. 2014. Importance of food-demand management for climate mitigation. *Nat. Clim. Change* 4:924–29
71. Schmitz C, van Meijl H, Kyle P, Nelson GC, Fujimori S, et al. 2014. Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. *Agric. Econ.* 45(1):69–84

72. Grassini P, Eskridge KM, Cassman KG. 2013. Distinguishing between yield advances and yield plateaus in historical crop production trends. *Nat. Commun.* 4:2918
73. Visconti P, Bakkenes M, Baisero D, Brooks T, Butchart SHM, et al. 2016. Projecting global biodiversity indicators under future development scenarios. *Conserv. Lett.* 9(1):5–13
74. Laurance WF, Lovejoy TE, Vasconcelos HL, Bruna EM, Didham RK, et al. 2002. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. *Conserv. Biol.* 16(3):605–18
75. Haddad NM, Brudvig LA, Clobert J, Davies KF, Gonzalez A, et al. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. *Sci. Adv.* 1(2):e1500052
76. Storkey J, Meyer S, Still KS, Leuschner C. 2012. The impact of agricultural intensification and land-use change on the European arable flora. *Proc. R. Soc. B* 279:1421–29
77. Bouwman AF, Beusen AHW, Billen G. 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050. *Glob. Biogeochem. Cycles* 23(4). **https://doi.org/10.1029/2009GB003576**
78. Bodirsky BL, Popp A, Lotze-Campen H, Dietrich JP, Rolinski S, et al. 2014. Reactive nitrogen requirements to feed the world in 2050 and potential to mitigate nitrogen pollution. *Nat. Commun.* 5(May):3858
79. Bouwman L, Goldewijk KK, Van Der Hoek KW, Beusen AH, Van Vuuren DP, et al. 2013. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *PNAS* 110(52):20882–87
80. Tilman D, Fargione J, Wolff B, D'Antonio C, Dobson A, et al. 2001. Forecasting agriculturally driven global environmental change. *Science* 292(April):281–84
81. Hoekstra AY, Mekonnen MM. 2012. The water footprint of humanity. *Proc. Natl. Acad. Sci.* 109(9):3232–37
82. Moran A, Gu D, Zhao D, Coxson P, Wang YC, et al. 2010. Future cardiovascular disease in China: Markov model and risk factor scenario projections from the coronary heart disease policy model—China. *Circ. Cardiovasc. Qual. Outcomes* 5:243–52
83. Heidenreich PA, Trogdon JG, Khavjou OA, Butler J, Dracup K, et al. 2011. Forecasting the future of cardiovascular disease in the United States. *Circulation* 123(8):933–44
84. Beaglehole R, Bonita R. 2008. Global public health: a scorecard. *Lancet* 372(9654):1988–96
85. Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A. 2016. The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: a systematic review. *PLOS ONE* 11(11):e0165797
86. Heller MC, Keoleian GA. 2014. Greenhouse has emission estimates of U.S. dietary choices and food loss. *J. Ind. Ecol.* 19(3):391–401
87. Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, et al. 2012. Sustainable diets for the future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet? *Am. J. Clin. Nutr.* 96(2):632–39
88. Pan A, Sun Q, Bernstein AM, Schulze MB, Manson JE, et al. 2012. Red meat consumption and mortality: results from 2 prospective cohort studies. *Arch. Intern. Med.* 172(7):555–63
89. Vieux F, Darmon N, Touazi D, Soler LG. 2012. Greenhouse gas emissions of self-selected individual diets in France: changing the diet structure or consuming less? *Ecol. Econ.* 75:91–101
90. Key TJ, Appleby PN, Spencer EA, Travis RC, Roddam AW, Allen NE. 2009. Mortality in British vegetarians: results from the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford). *Am. J. Clin. Nutr.* 89(suppl 5):1613S–19S
91. Smith J, Sones K, Grace D, MacMillan S, Tarawali S, et al. 2013. Beyond milk, meat, and eggs: role of livestock in food and nutrition security. *Anim. Front.* 3(1):6–13
92. Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA. 2012. Closing yield gaps through nutrient and water management. *Nature* 490(7419):254–57
93. Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, et al. 2010. Food security: the challenge of feeding 9 billion people. *Science* 327:812–18
94. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, et al. 2011. Solutions for a cultivated planet. *Nature* 478(7369):337–42
95. West P, Gerber J, Engstrom P, Mueller N, Brauman K, et al. 2014. Leverage points for improving global food security and the environment. *Science* 345:325–28

96. Vandermeer J. 1989. *The Ecology of Intercropping*. Cambridge, UK: Cambridge Univ. Press
97. Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. 2002. Agricultural sustainability and intensive production practices. *Nature* 418(6898):671–77
98. Dorward A, Chirwa E. 2011. The Malawi agricultural input subsidy programme: 2005/06 to 2008/09. *Int. J. Agric. Sustain.* 9:232–47
99. Druilhe Z, Barreiro-Hurlé J. 2012. *Fertilizer subsidies in Sub-Saharan Africa*. Work. Pap., Agric. Dev. Econ. Div., Food Agric. Organ. U. N., Rome
100. Khan ZR, Midega CAO, Pittchar JO, Murage AW, Birkett MA, et al. 2014. Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. *Proc. R. Soc. B* 369:1–11
101. Hall NM, Kaya B, Dick J, Skiba U. 2006. Effect of improved fallow on crop productivity, soil fertility and climate-forcing gas emissions in semi-arid conditions. *Biol. Fertile Soils* 42:224–30
102. Garrity DP, Akinnifesi FK, Ajayi OC. 2010. Evergreen agriculture: a robust approach to sustainable food security in Africa. *Food Secur.* 2:197–214
103. Lobell DB, Cassman KG, Field CB. 2009. Crop yield gaps: their importance, magnitudes, and causes. *Annu. Rev. Environ. Resour.* 34:179–204
104. Gustavsson J, Cederberg C, Sonesson U, van Otterdijk R, Meybeck A. 2011. *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Rome: Food Agric. Organ., U. N.
105. Kummu M, de Moel H, Porkka M, Siebert S, Varis O, Ward PJ. 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Sci. Total Environ.* 438:477–89
106. Lipinski B, Hanson C, Lomax J, Kitinoja L, Waite R, Searchinger T. 2013. *Reducing Food Loss and Waste*. Washington, DC: World Res. Inst.
107. Robertson GP, Vitousek PM. 2009. Nitrogen in agriculture: balancing the cost of an essential resource. *Annu. Rev. Environ. Resour.* 34(1):97–125
108. Vitousek PM, Naylor R, Crews T, David MB, Drinkwater LE, et al. 2009. Nutrient imbalances in agricultural development. *Science* 324:1519–20
109. Ward MH, Theo M, Levallois P, Brender J, Gulis G, et al. 2005. Workgroup report: Drinking-water nitrate and health—recent findings and research needs. *Environ. Health Perspect.* 113(11):1607–14
110. Heathwaite AL, Griffiths P, Parkinson RJ. 1998. Nitrogen and phosphorus in runoff from grassland with buffer strips following application of fertilizers and manures. *Soil Use Manag.* 14:142–48
111. Borin M, Passoni M, Thiene M, Tempesta T. 2010. Multiple functions of buffer strips in farming areas. *Eur. J. Agron.* 32:103–11
112. Schulte LA, Niemi J, Helmers MJ, Liebman M, Arbuckle JG, et al. 2017. Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn-soybean croplands. *PNAS* 114(42):11247–52
113. European Community. 1991. Council directive concerning the protection of waters against pollution caused by nitrates from agricultural sources. *Off. J. Eur. Commun.* **https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31991L0676&from=EN**
114. European Commission. 2013. *Report from the commission to the council and the European parliament on the implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2008–2011*. Rep., Eur. Comm. **https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0683&from=en**
115. Butchart SHM, Clarke M, Smith RJ, Sykes RE, Scharlemann PW, et al. 2015. Shortfalls and solutions for meeting national and global conservation area targets. *Conserv. Lett.* 8(October):329–37
116. Packer C, Loveridge A, Canney S, Caro T, Garnett ST, et al. 2013. Conserving large carnivores: dollars and fence. *Ecol. Lett.* 16(5):635–41
117. Cawthorn D-M, Hoffman LC. 2015. The bushmeat and food security nexus: a global account of the contributions, conundrums and ethical collisions. *Food Res. Int.* 76(4):906–25
118. Polasky S, Nelson E, Camm J, Csuti B, Fackler P, et al. 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biol. Conserv.* 141(6):1505–24
119. Seufert V, Ramankutty N, Foley JA. 2012. Comparing the yields of organic and conventional agriculture. *Nature* 485(7397):229–32

120. Seufert V, Ramankutty N. 2017. Many shades of gray—the context-dependent performance of organic agriculture. *Sci. Adv.* 3(3):e1602638
121. Gattinger A, Muller A, Haeni M, Skinner C, Fliessbach A, et al. 2012. Enhanced top soil carbon stocks under organic farming. *PNAS* 109(44):18226–31
122. Mäder P, Fließbach A, Dubois D, Gunst L, Fried P, Niggli U. 2002. Soil fertility and biodiversity in organic farming. *Science* 296(5573):1694–97
123. Bengtsson J, Ahnström J, Weibull AC. 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *J. Appl. Ecol.* 42(2):261–69
124. Hole DG, Perkins AJ, Wilson JD, Alexander IH, Grice PV, Evans AD. 2005. Does organic farming benefit biodiversity? *Biol. Conserv.* 122(1):113–30
125. Baker BP, Benbrook CM, Groth E, Lutz Benbrook K. 2002. Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets. *Food Addit. Contam.* 19(5):427–46
126. Hunter D, Foster M, McArthur JO, Ojha R, Petocz P, Samman S. 2011. Evaluation of the micronutrient composition of plant foods produced by organic and conventional agricultural methods. *Crit. Rev. Food Sci. Nutr.* 51:571–82
127. Palupi E, Jayanegara A, Ploeger A, Kahl J. 2012. Comparison of nutritional quality between conventional and organic dairy products: a meta-analysis. *J. Sci. Food Agric.* 92(14):2774–81
128. Dangour A, Lock K. 2010. Nutrition-related health effects of organic foods: a systematic review. *AJCN* 92(8):203–10
129. Mukherjee A, Speh D, Dyck E, Diez-Gonzalez F. 2004. Preharvest evaluation of coliforms, *Escherichia coli*, *Salmonella*, and *Escherichia coli* O157:H7 in organic and conventional produce grown by Minnesota farmers. *J. Food Prot.* 67(5):894–900
130. Davis AS, Hill JD, Chase CA, Johanns AM, Liebman M. 2012. Increasing cropping system diversity balances productivity, profitability and environmental health. *PLOS ONE* 7(10):e47149
131. Breslin PAS. 2013. An evolutionary perspective on food and human taste. *Curr. Biol.* 23(9):R409–18
132. Smil V. 2002. Eating meat: evolution, patterns, and consequences. *Popul. Dev. Rev.* 28(4):599–639
133. Ludwig DS, Nestle M. 2008. Can the food industry play a constructive role in the obesity epidemic? *JAMA* 300(15):1808–11
134. Story M, Kaphingst KM, Robinson-O'Brien R, Glanz K. 2008. Creating healthy food and eating environments: policy and environmental approaches. *Annu. Rev. Public Health.* 29(1):253–72
135. Wansink B. 1996. Can package size accelerate usage volume? *J. Mark.* 60(3):1
136. de Castro JM, Brewer EM. 1992. The amount eaten in meals by humans is a power function of the number of people present. *Physiol. Behav.* 51(1):121–25
137. De Castro JM. 2000. Eating behavior: lessons from the real world of humans. *Nutrition.* 16(10):800–13
138. Larson NI, Neumark-Sztainer D, Hannan PJ, Story M. 2007. Family meals during adolescence are associated with higher diet quality and healthful meal patterns during young adulthood. *J. Am. Diet. Assoc.* 107(9):1502–10
139. Cochero MA, Rivera-Dommarco J, Popkin BM, Ng SW. 2017. In Mexico, evidence of sustained consumer response two years after implementing a sugar-sweetened beverage tax. *Health Aff.* 36(3):564–71
140. Falbe J, Thompson HR, Becker CM, Rojas N, Mcculloch CE, Madsen KA. 2016. Impact of the Berkeley excise tax on sugar-sweetened beverage consumption. *Am. J. Public Health* 106(10):1865–71
141. Jensen JD, Smed S. 2013. The Danish tax on saturated fat—short run effects on consumption, substitution patterns and consumer prices of fats. *Food Policy* 42:18–31
142. Dewey C. 2017. Why Chicago's soda tax fizzled after two months—and what it means for the anti-soda movement. *Washington Post*, Oct. 10. **https://www.washingtonpost.com/news/wonk/wp/2017/10/10/why-chicagos-soda-tax-fizzled-after-two-months-and-what-it-means-for-the-anti-soda-movement/?noredirect=on&utm_term=.27e8774da6c7**
143. Vallgårda S, Holm L, Jensen JD. 2015. The Danish tax on saturated fat: why it did not survive. *Eur. J. Clin. Nutr.* 69(2):223–26
144. Ollberding NJ, Wolf RL, Contento I. 2010. Food label use and its relation to dietary intake among US adults. *J. Am. Diet. Assoc.* 110(8):1233–37

145. Sonnenberg L, Gelsomin E, Levy DE, Riis J, Barraclough S, Thorndike AN. 2013. A traffic light food labeling intervention increases consumer awareness of health and healthy choices at the point-of-purchase. *Prev. Med.* 57(4):253–57
146. Thorndike AN, Riis J, Sonnenberg LM, Levy DE. 2014. Traffic-light labels and choice architecture: promoting healthy food choices. *Am. J. Prev. Med.* 46(2):143–49
147. Vanclay JK, Shortiss J, Aulsebrook S, Gillespie AM, Howell BC. 2011. Customer response to carbon labelling of groceries. *J. Consum. Policy* 34:153–60
148. Swartz JJ, Braxton D, Viera AJ. 2011. Calorie menu labeling on quick-service restaurant menus: an updated systematic review of the literature. *Int. J. Behav. Nutr. Phys. Act.* 8(1):135
149. Fischer CG, Garnett T. 2016. *Plates, Pyramids, Planet*. Oxford, UK: FAO, Univ. Oxford
150. Springmann M, Mason-D'Croz D, Robinson S, Wiebe K, Godfray HCJ, et al. 2016. Mitigation potential and global health impacts from emissions pricing of food commodities. *Nat. Clim. Change* 7(1):69–74