Alignment of Healthy Dietary Patterns and Environmental Sustainability: A Systematic Review[1,2]

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ABSTRACT

To support food security for current and future generations, there is a need to understand the relation between sustainable diets and the health of a population. In recent years, a number of studies have investigated and compared different dietary patterns to better understand which foods and eating patterns have less of an environmental impact while meeting nutritional needs and promoting health. This systematic review (SR) of population-level dietary patterns and food sustainability extends and updates the SR that was conducted by the 2015 US Dietary Guidelines Advisory Committee, an expert committee commissioned by the federal government to inform dietary guidance as it relates to the committee's original conclusions. In the original SR, 15 studies met the criteria for inclusion; since then, an additional 8 studies have been identified and included. The relations between dietary intake patterns and both health and environmental outcomes were compared across studies, with methodologies that included modeling, life cycle assessment, and land use analysis. Across studies, consistent evidence indicated that a dietary pattern higher in plant-based foods (e.g., vegetables, fruits, legumes, seeds, nuts, whole grains) and lower in animal-based foods (especially red meat), as well as lower in total energy, is both healthier and associated with a lesser impact on the environment. This dietary pattern differs from current average consumption patterns in the United States. Our updated SR confirms and strengthens the conclusions of the original US Dietary Guidelines Advisory Committee SR, which found that adherence to several well-characterized dietary patterns, including vegetarian (with variations) diets, dietary guidelines–related diets, Mediterranean-style diets, the Dietary Approaches to Stop Hypertension (DASH) diet, and other sustainable diet scenarios, promotes greater health and has a less negative impact on the environment than current average dietary intakes. *Adv Nutr* 2016;7:1005–25.

Keywords: food security, sustainable diets, dietary guidelines, dietary patterns, life cycle assessment, systematic review

Introduction

Nutrition and food policy experts in the United States have long been concerned with the food security of the public. These concerns typically have been framed in the here and now; however, as a greater understanding of the human impact on the biosphere emerges, we recognize that actions taken now affect or constrain future choices. Hence, it is important to understand how our actions (dietary patterns and choices) in 2016 affect the potential for food security in the future. Long-term food security can be ensured only if we consider the sustainability of our food supply now.

Two established definitions from the FAO are relevant to this work (1, 2). *Food security* exists when all people at all times have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active, healthy life. *Sustainable diets* are those diets that have low environmental impact and contribute to food and nutrition security and a healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems; culturally acceptable; accessible; economically fair; affordable; and nutritionally adequate, safe, and healthy while optimizing natural and human resources.

Dietary patterns are defined as the quantities, proportions, variety, or combinations of different foods and beverages in diets and the frequency with which they are habitually consumed (3). The current emphasis on healthy eating patterns,

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rather than individual food groups, foods, or nutrients, provides a more comprehensive approach to assess both health and environmental outcomes related to the US diet. Considerable evidence exists on a priori dietary patterns that promote health, including the Dietary Approaches to Stop Hypertension (DASH)[8] diet, the Mediterranean dietary pattern (MDP), vegetarian diets and their variations, and the Healthy US-Style Eating Pattern (3). These patterns, consumed at an appropriate caloric concentration, promote healthy growth and development while reducing the risk of preventable chronic diseases, including cardiovascular diseases, type 2 diabetes, obesity, and some cancers. Furthermore, these patterns of eating promote functional health in older adults (3).

The capacity to produce enough food in the future is limited potentially by water, soil fertility, land use, and stewardship of seas and oceans. There is mounting evidence that the impact of food production on the environment is considerable. Natural resources will be strained and may be lost to future generations if energy, water, and land are not managed and conserved responsibly. Looked at within a planetary boundary framework, the food production system affects a variety of natural resources (4). The global system is responsible for >70% of fresh water use, up to 30% of human-generated greenhouse gas (GHG) emissions, and 80% of deforestation (5). Food production also is the largest contributor to the loss of biodiversity (5). Large phosphorus flows into surface waters from agriculture lead to the degradation of freshwater and hypoxic zones in both freshwater and salt water (6). Population growth, energy costs, and climate change will continue to strain the available natural resources while the transition in nutrition in much of the developing world threatens to overwhelm global food production capacity (7).

Four mutually supportive approaches are needed to meet present and future food needs: *1*) shift individual and population food choices and patterns, *2*) implement existing and develop new agricultural production practices that reduce ecological effects and conserve resources while continuing to meet food and nutritional needs, *3*) more equitably distribute resources, and *4*) reduce food waste at various points in the supply chain and by consumers (8). Our analysis focuses primarily on the first approach, examining the effect of population-level dietary choices on sustainability.

The Dietary Guidelines Advisory Committee (DGAC) addressed this issue in the Scientific Report of the DGAC, released in February 2015 (3). All authors were either members of or consultants to the DGAC. This systematic review (SR) was undertaken to capture what is clearly an evolving research base on the link between dietary patterns and environmental outcomes. The main objective of our SR was to update the DGAC report analysis. Our approach was to assess the alignment between food patterns that are nutritionally sound and support health and those that are more environmentally sustainable. Intergovernmental organizations also have used this strategy. The FAO identified MDP as an example of a sustainable diet because of its smaller meat portions and emphasis on plant-based dietary diversity, and the European Commission supported the creation of the LiveWell for LIFE diet to promote health and reduce GHG emissions (9, 10).

Research in the area of sustainability and dietary patterns is advancing quickly, and the methods for assessing dietary patterns in populations and life cycle analysis (LCA) have made substantial advances (11). The growing evidence base for this question exemplifies this in that numerous peer-reviewed articles have been published since the publication of the DGAC SR. To fully encompass this state-of-the-art body of evidence, we undertook an update of the DGAC document and assessed research published between January 2014 and July 2015. This will help determine whether there is further evidence supporting or contradicting the conclusions drawn by the 2015 DGAC SR.

Methods

An analytical framework was developed to identify the core elements of the SR question what is the relation between population-level dietary patterns that promote health and long-term food sustainability? In developing the SR protocol, we used the population, intervention or exposure, comparator, and outcomes question framework (12). These 4 components represent key features of the subject matter that need to be considered in developing an SR framework (**Figure 1**).

The original search of PubMed, Cochrane, Embase, and Navigator databases was completed in March 2014 (3). As outlined in the DGAC report, the inclusion criteria identified original research articles published in peer-reviewed English-language journals having subjects who were healthy or at elevated chronic disease risk hailing from countries with high or extremely high human development indexes. Study designs included randomized and nonrandomized controlled trials, prospective cohort studies, cross-sectional studies, case-control studies, and modeling studies. Studies that examined low-calorie diets for weight loss purposes and other treatment diets were excluded. Finally, studies were required to include a description of a dietary pattern, an associated health outcome, and sustainability or food security outcomes. The identical inclusion criteria were used for our update of the SR, which spanned the literature published between January 2014 and July 2015.

The search and selection of relevant studies, data abstraction, and grading of the evidence were conducted as originally described (3). We used a data extraction grid to compile data and environmental outcomes. A modified critical appraisal checklist was used to assess individual study quality and risk of bias, and 2 experts in the field of food sustainability who served as consultants to the DGAC reviewed these assessments. The critical appraisal checklist is used to assess studies that use modeling to extrapolate the progression of clinical outcomes, transform final outcomes from intermediate measures, examine relations between inputs and outputs to apportion resource use, and extrapolate findings from one clinical setting or population to another. To attain a high score, studies must report the variables that have been modeled rather than directly observed, which additional variables have been included or excluded, which statistical relations have been assumed, and the evidence that supports these assumptions (3, 13–15).

Results

Review of the evidence

Fifteen studies met the inclusion criteria for the original SR (**Figure 2**) (15–29). After completion of the original SR and the DGAC advisory process, an update of the evidence was conducted

[8] Abbreviations used: ADD, average Dutch diet; DASH, Dietary Approaches to Stop Hypertension; DGAC, Dietary Guidelines Advisory Committee; EPIC, European Prospective Investigation into Cancer; GHG, human-generated greenhouse gas; LCA, life cycle analysis; MDP, Mediterranean dietary pattern; NND, New Nordic Diet; RPM, red and processed meats; SR, systematic review; S&H, sustainable and healthy.

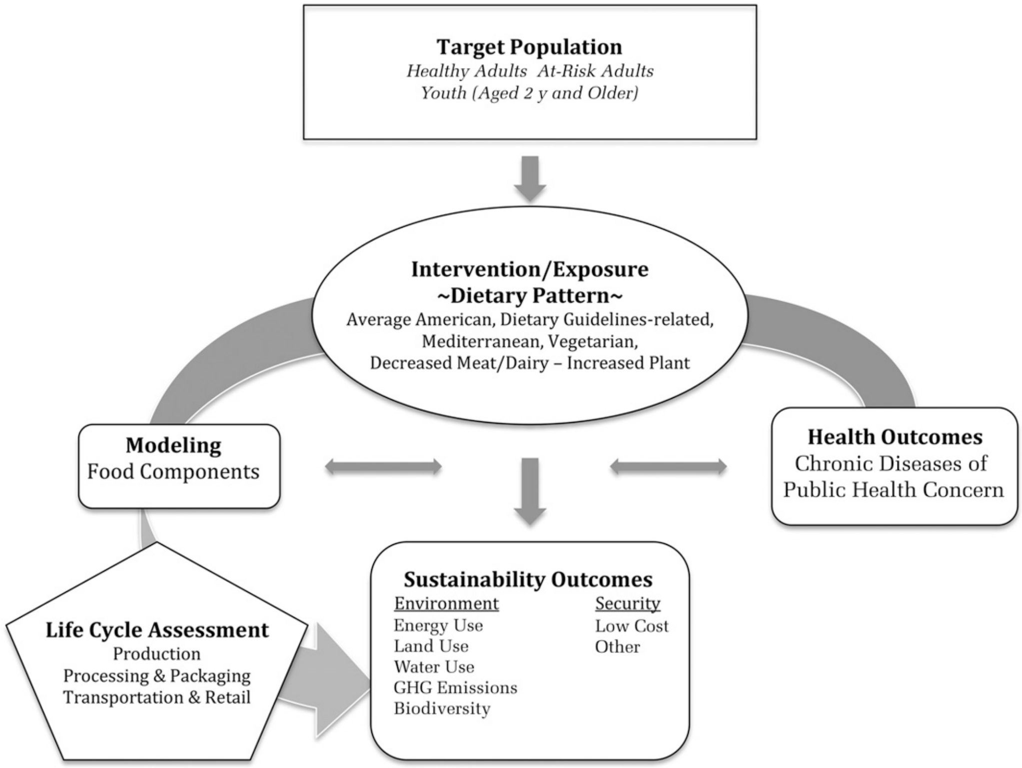

FIGURE 1 Analytical framework.

to identify additional studies that met the inclusion criteria and determine whether there were any substantive changes in the science. The update identified 8 additional studies that met the inclusion criteria (Figure 2). These additional studies consisted mainly of dietary pattern–modeling studies or cross-sectional diet studies that assessed related environmental and health outcomes; one was a prospective cohort study with a 16-y follow-up of the European Prospective Investigation into Cancer (EPIC)–Netherlands cohort (30). Details of the studies are presented in **Table 1**. These studies were published from 2003 to 2014 in the original SR and from 2014 to 2015 in the update. Studies were based on populations in the United States, New Zealand, the United Kingdom, the Netherlands, Germany, Spain, France, Italy, Brazil, and Australia. Dietary patterns that were examined included the average and dietary guidelines–related patterns of the respective countries, various vegetarian patterns (e.g., lacto-ovo vegetarian, vegan), the MDP, pescatarian, the DASH diet, and several diets based on sustainable outcomes and/or cost. The average dietary pattern of the respective country was the most frequent dietary comparison, although several studies made further comparisons with many of the above-noted dietary patterns. Additional approaches were used to examine modeling scenarios with various replacements of animal-based foods with plant-based foods.

Most modeling studies [e.g., German National Nutrition Surveys (22), the National Diet and Nutrition Survey from the United Kingdom (16, 21), the National Nutrition Survey from Australia (20)] used cross-sectional assessment of dietary patterns from surveys of representative adult populations. The average dietary patterns were compared with modeled food patterns, such as MDP or vegetarian, as described in detail below. These findings are generalizable to the US population because the studies were conducted in countries that are highly developed and had created dietary guidelines. Using a modified critical appraisal checklist, we found that the study quality for the body of evidence reviewed was high, with scores ranging from 7 of 12 to 12 of 12.

Across the original and updated SR, health outcomes associated with the dietary patterns were based most often on various vegetarian dietary patterns, dietary guidelines–related patterns, the DASH diet, or the MDP. Diet quality was evaluated in some studies using an index, such as the Healthy Eating Index (37) or the WHO Technical Report Series (38). Some studies also modeled health outcomes; for example, one study assessed the interaction between health and sustainability scores through use of the WHO Technical Report Series and the LCA sustainability score to measure combined nutritional and ecological value (28). In addition, Scarborough et al. (27) used the DIETRON model to estimate deaths delayed or averted for each dietary pattern.

The environmental impacts that were most commonly modeled were GHG emissions and use of resources such as water, energy, and land used for agriculture. Overall, the original SR and the update included 18 studies on GHG (14–16, 20–22, 26–31, 35, 36); 4 studies on energy use (22, 25, 26) and 3 studies on water use (22, 24, 26). Certain studies assessed other environmental metrics, including average impact

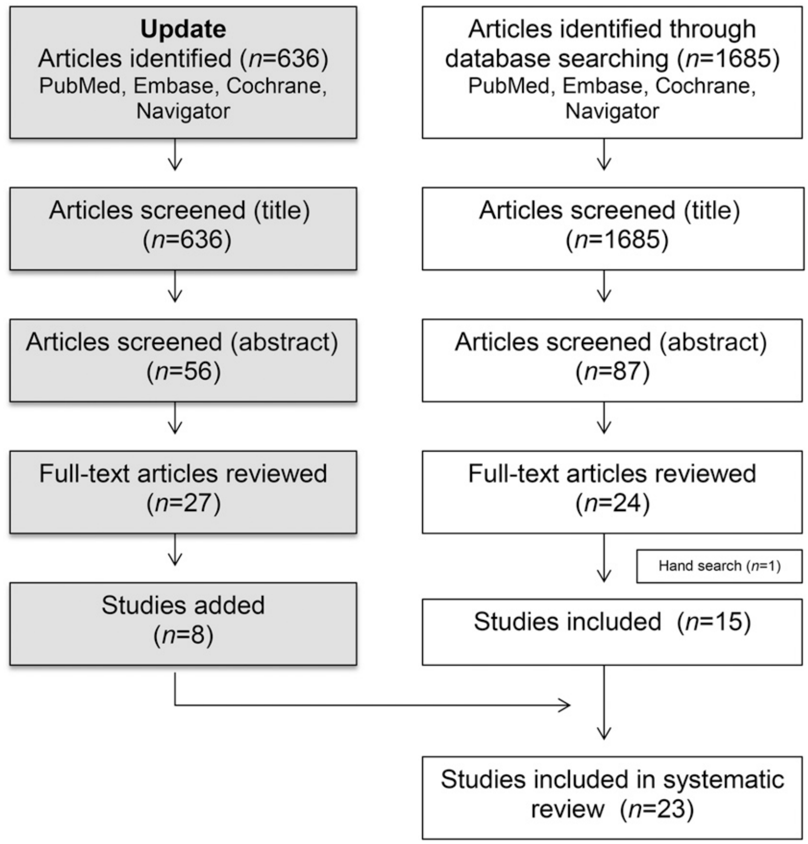

FIGURE 2 Literature search and selection flowchart.

on the ecosystem (17), carrying capacity (individuals supported) (23), and global warming potential (34). One study assessed blue water use, which includes fresh surface water and groundwater such as lakes, rivers, and aquifers (22).

In general, the environmental impact of the dietary patterns was assessed by using LCA methodology. We analyzed the ecological impact of each food and/or food category being assessed. LCA is a standardized methodological framework for assessing the environmental impact (or load) attributable to the life cycle of a food product. The life cycle of a food typically includes agricultural production, processing and packaging, transportation, retail, use, and waste disposal. An inventory of all of the stages of the life cycle is determined for each food product, and a weight or number of points is attributed to each food or food category based on impacts on the environment (3). These results can be translated into measures of impact on energy resources, ecosystem quality, and population health using programs such as Eco-Indicator (39). In addition to the health assessment tools listed above, some studies used a standardized approach to LCA analysis to determine damage from GHG emissions and use of resources such as damage to human health–related outcomes, including the number and duration of disease and life-years lost resulting from premature death from environmental causes. It should be noted that not every stage of the life cycle was assessed in all of the included studies. The specifics on included LCA stages are detailed in Table 1. In addition, the number of foods that have been evaluated through use of LCA is limited and therefore requires extrapolation to assess complete dietary patterns.

Fewer studies assessed food security, and they did so in terms of cost differences, usually between an average dietary pattern for the population and a sustainable dietary pattern for that country (13, 18, 21, 29, 31–34). The basic food basket concept was used in one study (18), representing the cost for a 2-adult/2-child household.

Dietary patterns in relation to health and sustainability outcomes

Vegetarian and omnivorous diets. Several studies surveyed variations in vegetarian diets or a range of diets from vegan to omnivorous dietary patterns and associated health and environmental outcomes (17, 23, 24). These studies examined dietary patterns ranging from low-fat, lacto-ovo vegetarian diets to high-animal-fat, meat-rich omnivorous diets (23). The findings from these studies showed that reduced meat consumption was expected to improve health outcomes and decrease GHG emissions and land, energy, and water usage. In Italy, beef was the food with the greatest projected impact on resources and the ecosystem. The average diet in Italy had the highest environmental impact and lowest health score, whereas the vegan diet demonstrated the lowest environmental impact and highest health score (17). In the United States, the average meat-based diet was compared with a lacto-ovo vegetarian diet. This analysis showed that energy, land, and water usage were higher for the meat-based diet than for the

TABLE 1 Summary of studies on dietary patterns and sustainability[1]

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost		Summary of findings	Study limitations
				Dietary pattern	Food components		
Aston et al., 2012 (16), modeling and data analysis, United Kingdom	2 Dietary patterns: *1)* counterfactual diet (combination of lowest RPM + vegetarian) and *2)* current United Kingdom diet RPM consumption from the National Diet and Nutrition Survey of British Adults; counterfactual United Kingdom diet: vegetarians in survey population doubled and remainder adopted dietary pattern of lowest fifth of RPM consumers	CHD risk decrease: male average, 9.7% (range: 3.6–22.0%); female average, 6.4% (range: 1.8–14.3%) Diabetes risk decrease: men, 12.0% (range: 4.5–22.7%); women, 7.5% (range: 0.5–14.5%) CRC risk decrease: male average, 12.2% (range: 6.4–18.0%); female average: 7.7% (range: 4.0–11.3%)	LCA: all steps in production	GHG emissions: counterfactual diet decreased GHG by 0.47 kg CO_2eq · person^{-1} · d^{-1} (12%) to 3.96 kg CO_2eq · person^{-1} · d^{-1} in men and 3.02 kg CO_2eq · person^{-1} · d^{-1} in women vs. current diet Total GHG reduction of 27.8 million tons/y (3% of current total for the United Kingdom)	GHG emissions: red meat accounted for 31% of dietary CO_2eq emissions in men and 27% in women; processed meat accounted for an additional 10% and 8% in men and women, respectively (habitual RPM 2.5 times higher in top fifth vs. bottom fifth)	General adoption of a low-RPM diet, already consumed by a fraction of the United Kingdom population, would result in multiple benefits to health and environment. Dietary guidance should no longer be based on direct health effects alone. United Kingdom government has acknowledged environmental impact of livestock production, but changes in production will be insufficient to meet emission reduction targets. Joint producer and consumer responsibility is needed, supported by use of both production- and consumption-based GHG accounts.	Outdated dietary intake data (>10 y ago)
Baroni et al., 2006 (17), modeling and data analysis, Italy	7 Dietary patterns: *1)* OMNIV-INT, *2)* OMNIV-BIO, *3)* VEGET-INT, *4)* VEGET-BIO, *5)* VEGAN-INT, *6)* VEGAN-BIO, and *7)* NORM-INT	Average health impact (points): OMNIV-INT, 0.46; OMNIV-BIO, 0.20; VEGET-INT, 0.34; VEGET-BIO, 0.18; VEGAN-INT, 0.15; VEGAN-BIO, 0.04; NORM-INT, 1.06 From omnivorous diets: 3–4% of environmental impact from eutrophication, 5–13% from land use, 15–18% from damage to respiration from inorganic chemicals, 20–26% from consumption of fossil fuels, 41–46% from water use	LCA: from extraction and processing to production, transportation, distribution, use, and waste with use of 3 different LCA perspectives: individual, hierarchical, and egalitarian	Average resources impact (points): OMNIV-INT, 1.42; OMNIV-BIO, 0.80; VEGET-INT, 0.88; VEGET-BIO, 0.59; VEGAN-INT, 0.54; VEGAN-BIO, 0.46; NORM-INT, 3.70 (from omnivorous diets: 20–26% from fossil fuels, 5–13% from land use, and 41–46% from water) Average ecosystem impact (points): OMNIV-INT, 0.27; OMNIV-BIO, 0.27; VEGET-INT, 0.17; VEGET-BIO, 0.18; VEGAN-INT, 0.11; VEGAN-BIO, 0.07; NORM-INT, 0.65	Beef is the single food with greatest impact on environment; other high-impact foods were cheese, milk, and fish	VEGAN-BIO diet had the lowest environmental impact; NORM-INT diet had the greatest environmental impact. Within the same method of production, a greater consumption of animal products translated to a greater impact on the environment. The highest environmental impact of omnivorous diets resulted from water use.	Subsumes individual foods into overall categories for simplification.

(Continued)

TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost		Summary of findings	Study limitations
				Dietary pattern	Food components		
Barosh et al., 2014 (18), cross-sectional survey of food availability and cost, Australia	2 Dietary patterns: *1*) typical basket and *2*) S&H basket 2 Food baskets (typical and S&H) developed for 2-adult/2-child households in 5 socioeconomic districts; surveyed to estimate food cost, food availability, and accessibility in household income quintiles	S&H basket was developed according to health principles of Australian Dietary Guidelines and food items with lower environmental impact were chosen	NR	Cost: Cost of S&H basket is more than typical basket in 5 socioeconomic areas; most disadvantaged groups spent 30% more on S&H basket. Lowest-income quintile households: 33–44% of income spent on typical basket; 40–48% of income spent on S&H basket.	NR	Most economically disadvantaged groups (neighborhood and household levels) experienced the greatest inequality in affordability of S&H basket.	Variability in food item selection may introduce some bias. Food basket approach not necessarily representative of true diet composition and purchasing habits. Not able to account for differences in product quality.
Biesbroek et al., 2014 (30), prospective cohort (15.9 y) (EPIC-NL) and modeling, Netherlands	2 Dietary patterns: *1*) ADD and *2*) meat-substituted diet Modeling a substitution of 35 g total meat intake/d with equal amounts of potatoes; pasta, rice, and couscous; vegetables; fruit, nuts, and seeds; milk-based desserts; fish; or cheese	Total mortality: Comparing highest vs. lowest quartile of GHG [HR (95% CI): 1.00 (0.86, 1.17)]; also NS for cancer, CVD, and respiratory diseases Comparing highest vs. lowest quartile of land use [HR (95% CI): 1.05 (0.89, 1.23)] Modeling substitution of 35 g total meat/d had health benefits All-cause mortality risk decreased by 11% for pasta, rice, and couscous; 9% for vegetables; 6% for fruit, nuts, and seeds; and 19% for fish	LCA: production to waste	GHG emissions [median (IQR)]: quartile 1: 2.86 kg CO_2eq/d (2.56–3.07 kg CO_2eq/d); quartile 4: 5.12 kg CO_2eq/d (4.79–5.62 kg CO_2eq/d) Land use [median (IQR)]: quartile 1: 2.61 $m^2 \cdot$ y/d (2.31–2.82 $m^2 \cdot$ y/d); quartile 4: 4.80 $m^2 \cdot$ y/d (4.51–5.28 $m^2 \cdot$ y/d)	GHG emissions: Total meat intake: ~30% of total dietary-derived GHG and land use Dairy: 25% of GHG and 17% of land use Beverages: 13% of GHG and 16% of land use Modeling substitution of 35 g total meat intake/d had environmental benefits GHG emissions/d: decreased by 10.8% for potatoes; 10.1% for pasta, rice, and couscous; 10.0% for vegetables; 10.0% for fruit, nuts, and seeds; 10.0% for milk-based desserts; 4.5% for fish; and 0.6% for cheese vs. usual diet in EPIC-NL Land use/d: decreased by 11.3% for potatoes; 9.7% for pasta, rice, and couscous; 10.8% for vegetables; 10.3% for fruit, nuts, and seeds; 10.9% for milk-based desserts; 9.8% for fish; and 4.5% for cheese	No associations between dietary-derived GHG and land use and total mortality (all-cause or cause-specific) in the EPIC-NL cohort Modeled substitution of meat with other major food groups was associated with lower mortality risk and reduced environmental impact (especially substitution with vegetables; fruit, nuts, and seeds; fish; or pasta, rice, and couscous)	Substitution was limited to equivalent quantity in weight, rather than isocaloric or nutritional component equivalency. Dietary assessment took place in the 1990s. GHG can vary among items in a food group.

(*Continued*)

TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost		Summary of findings	Study limitations
				Dietary pattern	Food components		
de Carvalho et al., 2013 (19), cross-sectional health survey, Brazil	2 Dietary patterns: *1)* RPM and *2)* adherence to Brazilian Healthy Eating Index Study measured RPM intake in San Paulo, Brazil, and assessed impact on diet quality and environment	Adherence to the Brazilian Healthy Eating Index Average RPM intake was 138 g/d for men and 81 g/d for women	Estimated GHG emissions from total meat consumption, based on production of 1 kg Brazilian beef = 44 kg CO_2eq	GHG emissions from meat were estimated at 18,071,988 tons of CO_2eq, or 4% of total emitted by agriculture	81% of men and 58% of women consumed more RPM than recommended. Diet quality was inversely associated with excessive meat intake in men (higher energy, total fat, and saturated fat).	Production of meat consumed in survey accounted for ~4% of total GHG emitted by Brazilian agriculture that year. GHG emissions would be 50% lower if meat consumption did not exceed the maximum recommended by the WCRF (71.4 g/d).	Cross-sectional design based on 24-h recall
Hendrie et al., 2014 (20), modeling and data analysis and survey, Australia	4 Dietary patterns: *1)* average diet (average Australian diet), *2)* average diet with minimal noncore foods (similar to average diet with minimal inclusion of energy-dense, processed noncore foods), *3)* total diet (recommended dietary pattern consistent with Australian Dietary Guidelines), and *4)* foundation diet (recommended dietary pattern that meets the minimum nutrient and energy needs requirements for the population)	Health benefits of adhering to Australian Dietary Guidelines Core foods: red meat, chicken, fish, eggs, breads and cereals, fruit, vegetables, dairy foods, and unsaturated oils Noncore foods: snacks, soft drinks, coffee and tea, desserts and sweets, processed meats, SFAs, and alcohol	GHG from diets assessed by input-output model of Australian economy (up to point of purchase) Australian MRIO model GHG factors for fresh meat and meat products disaggregated into factors for fresh meat and meat products from beef cattle, sheep, and pigs	GHG emissions: Highest GHG: average Australian diet: 14.5 kg CO_2eq · $person^{-1}$ · d^{-1} Lowest GHG: foundation diet: 10.9 kg CO_2eq · $person^{-1}$ · d^{-1} (~25% lower than average Australian diet)	GHG emissions: food groups with the greatest contribution to diet-related GHG were red meat (8.0 kg CO_2eq · $person^{-1}$ · d^{-1}) and energy-dense, nutrient poor "noncore" foods (3.9 kg CO_2eq $person^{-1}$ · d^{-1}); noncore foods accounted for 27% diet-related GHG.	Reduction in noncore foods and consumption of recommended servings of core foods are strategies to benefit population health and the environment. Key food differences between the average Australian diet and recommended dietary patterns are more fruit, vegetables and legumes, and dairy. Recommended dietary patterns also contain fewer food and drinks high in saturated fat, added sugar, salt, or alcohol—referred to as noncore foods.	Limited data on environmental effects of Australian diets available; used input-output LCA rather than process LCA
Macdiarmid et al., 2012 (21), modeling and data analysis, United Kingdom	3 Dietary patterns: *1)* sustainable, *2)* sustainable w/acceptability constraints, and *3)* average United Kingdom Iterative modeling to produce a diet that met dietary requirements while minimizing GHG Acceptability constraints based on an	Benefits from dietary recommendations: modeled for nutrient intake based on United Kingdom diet recommendations for women aged 19–50 y Constraints set for energy, macronutrients, and 6 micronutrients (iron, folate, vitamin B-12,	LCA: primary production to point of distribution (~56% total GHG generated up to point of distribution in the United Kingdom)	GHG emissions: Sustainable: 0.39 kg CO_2eq/d; 90% GHG reduction from average United Kingdom diet (7 foods) Acceptability constraints: 2.43 kg CO_2eq/d; 36% GHG reduction from average United Kingdom diet (52 foods; diet includes meat, less than average United Kingdom diet) Diet cost:	Meat in the acceptability constraints diet was 60% of current intake for United Kingdom women and 48% of red meat intake Proportion of dairy was similar to current intakes but lower in fat	Sustainable diet that meets dietary requirements for health with lower GHG can be achieved without eliminating meat or dairy products or increasing consumer costs. From the 1990 baseline, the reduction in GHG will decline to	Environmental impact limited to GHG

(*Continued*)

TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost		Summary of findings	Study limitations
				Dietary pattern	Food components		
	average United Kingdom diet 7-d sample diet based on 82 food groups generated to ensure diet was realistic and acceptable	zinc, calcium, and sodium)		Acceptability constraints: $46/wk; 89% of average United Kingdom diet		30%, 25%, and 14% in 2010, 2020, and 2050, respectively, as the population grows.	
Masset et al., 2014 (13), cross-sectional study (INCA2), France	4 Dietary patterns: *1*) lower carbon, *2*) higher quality, *3*) more sustainable, *4*) average French Lower carbon: total diet-related GHG value lower than sex-specific median GHG value Higher quality: PANDiet score higher than sex-specific median score More sustainable: PANDiet score higher than the median score and diet-related GHG value lower than the median value	Adequacy of nutrient intake calculated with PANDiet index PANDiet is composed of an "adequacy" subscore that includes positive nutrients and a "moderation" subscore for nutrients to limit Higher score indicates better nutritional adequacy of diet Reference values were French nutritional recommendations for adults or European Union values	LCA: production to waste	GHG emissions: Men: average French: 4.69 kg CO_2eq/d; low carbon: 3.76 kg CO_2eq/d; higher quality: 4.81 kg CO_2eq/d; more sustainable: 3.79 kg CO_2eq/d Women: average French: 3.55 kg CO_2eq/d; low carbon: 2.80 kg CO_2eq/d; higher quality: 3.75 kg CO_2eq/d; more sustainable: 2.95 kg CO_2eq/d Diet cost: Men: average French: 8.63 €/d (US$11.88/d); low carbon: 7.29 €/d (US$10.04/d); higher quality: 9.04 €/d (US$12.44/d); more sustainable: 7.77 €/d (US$10.70/d) Women: average French: 6.69 €/d (US$9.21/d); low carbon: 5.59 €/d (US$7.70/d); higher quality: 7.17 €/d (US $9.87/d); more sustainable: 6.20 €/d (US$8.53/d)	GHG emissions: More sustainable diets, compared with average diet: meats and eggs lower; fish and fish products higher in men and not different in women; dairy products not different; fruit, vegetables, and nuts higher; lowest content of alcoholic drinks, salty snacks, desserts, butter and cream, and mixed dishes with animal ingredients Meats, including ruminant and delicatessen meats, were the largest contributors to daily GHG in the average diet Including fish and dairy products, foods of animal origin (excluding mixed dishes) accounted for ∼45% of daily GHG and 25% of total energy in the average diet The contribution of foods of animal origin to daily GHG was reduced in more sustainable diets because of a reduction in ruminant-derived GHG ($P < 0.001$ in both sexes)	Reduction in diet-related GHG by 20% while maintaining high nutritional quality is possible. Goal could be achieved at no extra cost by reducing energy intake and energy density and increasing share of plant-based products.	More sustainable diets had only 2 sustainability criteria: lower GHG and higher nutritional quality, measured relative to medians. Did not include indirect land use change or food waste.
Meier and Christen, 2013 (22), modeling and data analysis, Germany	6 Dietary patterns: *1*) average German diet 1985–1989, *2*) average German diet 2006, *3*) DACH, *4*) alternative recommendations with UGB, *5*) lacto-ovo vegetarian, and *6*) vegan	Dietary guidelines and vegetarian/vegan-related health benefits	LCA: production, processing, transport and trade, packaging Input-output LCA/hybrid-LCA	Environmental effects per capita: CO_2 emissions, tons/y: 1985–1989 mean, 2.28; 2006 mean, 2.05; DACH, 1.82; UGB, 1.81; vegetarian, 1.56; vegan, 0.96 NH_3 emissions, kg/y: 1985–1989 mean, 7.7; 2006 mean, 6.5; DACH, 5.1; UGB, 4.7; vegetarian, 3.8; vegan, 0.7 Land use, m^2/y: 1985–1989 mean, 2.444; 2006 mean, 2.098;	Increasing legumes, nuts/seeds, and vegetables, instead of meat, butter, egg, and fish products (DACH > UGB > vegetarian > vegan) projected to reduce impact of diet if more in line with guidelines. GHG and phosphorus use: Compared with baseline 2006, DACH > UGB > vegetarian > vegan	Highest environmental impact would be from vegan and lacto-ovo vegetarian diets. Impact of UGB and DACH ranked third and fourth. All 4 diets achieved significant reductions compared with	Cradle-to-store boundaries of LCA Other LCA inconsistencies in input-output data and attributional vs. consequential approach

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TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost		Summary of findings	Study limitations
				Dietary pattern	Food components		
				DACH, 1.786; UGB, 1.740; vegetarian, 1.527; vegan, 1.052 Blue water use, m^3/y: 1985–1989 mean, 24.9; 2006 mean, 28.4; DACH, 20.9; UGB, 20.8; vegetarian, 52.5; vegan, 58.8 Phosphorus use, kg/y: 1985–1989 mean, 7.7; 2006 mean, 6.5; DACH, 5.7; UGB, 5.6; vegetarian, 4.5; vegan, 2.4 Primary energy use, GJ/y: 1985–1989 mean, 14.0; 2006 mean, 13.5; DACH, 12.5; UGB, 12.9; vegetarian, 11.2; vegan, 9.4	Increase from dairy (except vegan) Decrease from meat (except vegetarian and vegan) Ammonia and land use: decrease in shift to vegan (from meat and dairy) Blue water use: increase from fruit, nuts, and seeds	average German intake in 2006.	
Milner et al., 2015 (31), modeling and data analysis, United Kingdom	2 Dietary patterns: *1*) optimized United Kingdom diet and *2*) average United Kingdom diet Optimized United Kingdom diet met 2 criteria: *1*) meeting WHO nutrition recommendations (to conform to WHO recommendations, an optimized diet in the United Kingdom would contain less red meat, dairy products, eggs, and sweets and snacks, but more cereals, fruit, and vegetables) and *2*) reducing dietary GHG (average dietary intake patterns optimized to achieve target reductions of 10%, 20%, 30%, 40%, 50%, and 60% while meeting WHO recommendations)	YLL from CHD, stroke, several cancers and type 2 diabetes 50% GHG reduction: benefits for stroke and cancers peak at 50% GHG reduction and are lower for greater reductions 60% GHG reduction: results in large savings of >8.9 million YLL (30 y), but diet barely meets WHO guidelines and has relatively few foods	LCA: production to waste	GHG emissions: Optimized United Kingdom diet (meets WHO recommendations, but no GHG target), compared with the average United Kingdom diet resulted in a 17% decrease in GHG and would save ∼7 million YLL during a 30-y period GHG reduction targets were modeled further: 10%, 20%, 30%, 40%, 50%, and 60% reduction in GHG	GHG emissions: Shift in optimized United Kingdom diets as GHG reduced further, with increasingly more nonstarchy vegetables and less fruit (still more than the average United Kingdom diet), because vegetables are associated with lower GHG than fruit, on average As GHG targets were reduced, consumption of RPM in optimized United Kingdom diets was reduced and eventually removed (50–60% GHG)	Substantial benefits for health and climate change mitigation can be achieved in the United Kingdom by modifying existing diets to meet nutritional requirements while also reducing GHG. Simply optimizing diets to meet nutritional guidelines results in life expectancy gain of 8 mo at birth, primarily resulting from reductions in CHD. It is possible to maintain acceptability of diets with shifts in dietary patterns that provide >40% GHG reductions. To reduce emissions by >40%, major dietary changes that limit both acceptability and benefits to health are required.	National Diet and Nutrition Survey may underestimate food intake. Effects on morbidity not included. Limited health outcomes chosen to avoid double counting.

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TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost — Dietary pattern	Results: environment or cost — Food components	Summary of findings	Study limitations
Monsivais et al., 2015 (32), cross-sectional study (EPIC-Norfolk), United Kingdom	1 Dietary pattern: DASH diet adherence assessed by using a 130-item FFQ Adherence by DASH score of 8 food groups	Known association of DASH diet with decreased risk of hypertension and other chronic diseases	LCA: production to distribution with use of Audsley (33) United Kingdom–specific data	GHG emissions: highest quintile (quintile 5, highest adherence to DASH): 1.1 kg CO_2eq/d, 16% lower GHG than diets in quintile 1 Cost: diets in quintile 5 of DASH were US$1.03/d (18%) more costly than diets in quintile 1	GHG emissions: Accordance with 4 of the 8 food groups (fruit, whole grains, RPM, and dietary sodium) had a negative association with GHG; nuts and legumes group had a weak association with GHG Accordance with vegetable, low-fat dairy, and food high in sugars categories had a positive association with GHG Strongest (−) association (95% CI)—RPM: quintile 1 GHG, 8.59 kg CO_2eq/d (8.55, 8.63 kg CO_2eq/d); quintile 5 GHG, 4.34 kg CO_2eq/d (4.29, 4.38 kg CO_2eq/d) Strongest (+) association (95% CI): Vegetables—quintile 1 GHG, 5.77 kg CO_2eq/d (5.71, 5.83 kg CO_2eq/d); quintile 5 GHG, 6.70 kg CO_2eq/d (6.64, 6.76 kg CO_2eq/d) Foods high in added sugars—quintile 1 GHG, 5.84 kg CO_2eq/d (5.78, 5.90 kg CO_2eq/d); quintile 5 GHG, 6.80 kg CO_2eq/d (6.74, 6.86 kg CO_2eq/d)	Promoting wider uptake of the DASH diet in the United Kingdom may improve population health and reduce diet-related GHG. Some DASH food groups appear cost-neutral or provide cost savings, but affordability of DASH diet for lower-income groups must be assessed.	Cohort of older adults with limited socioeconomic and demographic heterogeneity CIs were likely underestimated because GHG uncertainty of individual foods was not incorporated. Diet cost limited to retail prices.
Peters et al., 2007 (23), modeling and data analysis, New York State	42 Dietary patterns, varying in total fat and meat servings: range from low-fat, lacto-vegetarian to high-fat, meat-rich omnivorous; 7 quantities of meat and eggs (0–381 g/d and 6 levels of fat; 20–45% of calories); 2308 kcal/d average energy requirement; excludes foods not produced in New York State; assumes seasonal limitations on fruit and vegetables; range to	Core diets were developed that, when possible, contained the Food Guide Pyramid–recommended servings of grains, vegetables, fruit, low-fat dairy, and low-fat protein sources	Annual per capita land requirements calculated based on dietary intake, crop yields, and livestock feed requirements	Land use: Per capita: 0.18 ha (0 g meat, 52 g fat); 0.86 ha (381 g meat, 52 g fat) Meat is the primary driver of increasing land use; fat increased land requirements for no-meat diets but reduced land requirements for high-meat diets 97.2% of the variability of land use between diets was attributable to quantity of meat Carrying capacity: 6.08 million people (0 g meat, 52 g fat); 2.04 million people (381 g meat, 52 g fat)	Land use: meat was the most land-intensive food, followed by eggs, dairy, fruit, oil, seeds, vegetables, beans, and grains; beef stood alone in requiring 31 times the land area as the equivalent quantity of grain	On balance, meat increases the land requirements of the diet more so than fat. Diets that include modest amounts of both meat and fat can feed slightly greater numbers of people than vegetarian diets that provide higher quantities of fat, however.	Per capita land requirements and carrying capacity are region specific.

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TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost — Dietary pattern	Results: environment or cost — Food components	Summary of findings	Study limitations
	represent prevalent consumption patterns in the United States			Lower-meat diets supported more people in terms of available land; as fats increased, there was less difference between diets with different meat levels 87.2% of the variability between diets was attributable to quantity of meat			
Pimentel and Pimentel, 2003 (24), modeling and data analysis, USA	2 Dietary patterns: *1)* lacto-ovo vegetarian, *2)* average US (meat-based diet) Meat-based diet based on food balance sheets for United States from FAOSTAT Composition of the lacto-ovo vegetarian diet was estimated by replacing meat and fish calories by proportionately increasing other foods consumed, except for sugar and sweeteners, fats, and vegetable oils	Health benefits of lacto-ovo vegetarian diet: 89 g protein/d is significantly lower than 112 g/d for meat-based diet but still in excess of RDA	NR	Land use: Cropland per capita needed for production: meat-based, 0.5 ha; vegetarian, 0.4 ha Amount of feed grains used to produce animal products for lacto-ovo vegetarian diet was approximately half the amount for the meat-based diet (450 vs. 816 kg/person) Water use: producing 1 kg of animal protein requires 100 times more water than 1 kg of grain protein	Energy use—fossil fuel energy required to produce 1 kcal of animal protein (kcal/kcal): lamb, 57/1; beef, 40/1; eggs, 39/1; swine, 14/1; dairy (milk), 14/1; turkey, 10/1; broilers, 4/1 Grain or forage required to produce 1 kg of animal product (kg/kg): lamb, 21/30; beef, 13/30; eggs, 11/0; swine, 5.9/0; turkeys, 3.8/0; broilers, 2.3/0; dairy (milk), 0.7/1 Plant protein requires 2.2 kcal/kcal The average of all fossil fuel:animal protein ratios is 25:1, or 11 times as high as for plant protein Red meat generally requires more resources to produce than nonmeat animal proteins (eggs, milk)	Meat-based diet requires more energy, land, and water resources, making the lacto-ovo vegetarian diet more sustainable than the current average US diet	Environmental impact limited to land, energy, and water resources.
Pradhan et al., 2013 (25), modeling and data analysis, global	16 Dietary patterns, grouped according to energy content: low calorie (patterns 1–3), moderate calorie (patterns 4–8), high calorie (patterns 9–11), and very-high calorie (patterns 12–16) Within each group, dietary patterns differed in composition of food groups Dietary patterns were characterized by using	Certain included dietary patterns have documented health benefits (e.g., MDP)	For estimating fossil fuel energy and GHG associated with dietary patterns, data were combined on agricultural energy input-output ratio, on agricultural non-CO_2 GHG, on feed supply, on	Energy use: high-calorie diets required high per capita energy inputs (1800–3500 kcal/d) GHG emissions: Per capita fossil fuel–related GHG ranged from 0.64 to 1.35 kg CO_2eq/d for very high–calorie diets to between 0.03 and 0.05 kg CO_2eq/d for low-calorie diets Non-CO_2 GHG were generally high for low- and moderate-calorie diets and resulted in high total GHG for those patterns For high- and very high–calorie	GHG emissions: non-CO_2 GHG higher for livestock (1.44–13.06 g CO_2eq/kcal) than for crops (0.31–1.81 g CO_2eq/kcal)	Low-calorie diets showed a similar emission burden to moderate- and high-calorie diets, which could be explained by a less efficient calorie production per unit of GHG in developing countries, which were mainly associated with low-calorie diets. Very high–calorie diets were prevalent in developed countries and	Global time series from FAOSTAT is assumed to be normally distributed, variables are assumed to be correlated, and data are assumed to exhibit stationarity.

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TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost		Summary of findings	Study limitations
				Dietary pattern	Food components		
	global time series data on food consumption and composition per country from FAOSTAT during 1961–2007 Data included 11 food groups: animal products, cereals, pulses, starchy roots, oil crops, vegetable oils, vegetables, fruit, sugar sweeteners, sugar crops, and alcoholic beverages		nutritive factors, and on food production	patterns, non-CO_2 GHG for crop and livestock were smaller, indicating that high-energy input and management strategies make agriculture more productive in developed countries, which were generally associated with higher-calorie patterns Total per capita GHG was only slightly higher for high- and very high–calorie diets (2.48–6.10 kg CO_2eq/d) vs. low- and moderate-calorie diets (1.43–4.48 kg CO_2eq/d)		were associated with high total per capita GHG due to high carbon intensity and high intake of animal products.	
Sáez-Almendros et al., 2013 (26), modeling and data analysis, Spain	4 Dietary patterns (comparable in energy content): *1*) MDP, *2*) SCP-FB, *3*) SCP-CS, and *4*) WDP MDP was obtained from the new MDP pyramid The Spanish dietary pattern was estimated from the FAOSTAT food balance sheets for 2007, and independently from the Household Consumption Surveys of the Spanish Ministry of Agriculture, Food and Environment WDP was also obtained from FAOSTAT food balance sheets for 2007	Documented health benefits of MDP	LCA: production, processing, packaging, transportation, and retail	GHG emissions, CO_2eq/y: MDP: 35,510; SCP-FB: 125,913; SCP-CS: 72,758; WDP: 217,128 Current world average: 62,389 Land use, 10^3 ha/y: MDP: 8365; SCP-FB: 19,874; SCP-CS: 12,342; WDP: 33,162 Current world average: 15,400 Energy use, tJ/y: MDP: 239,042; SCP-FB: 493,829; SCP-CS: 285,968; WDP: 611,314 Current world average: 229,178 Water use, km^3/y: MDP: 13.2; SCP-FB: 19.7; SCP-CS: 13.4; WDP: 22.0 Current world average: 19.4 Adherence to an MDP: decreased GHG, 72%; land use, 58%; energy, 52%; water, 33% Adherence to a WDP: increased all impact categories by 12–72%	GHG emissions: meat contributed the most for WDP and SCP, whereas dairy contributed most for MDP Land use: meat contributed the most for all diets except MDP, for which dairy contributed the most Energy use: dairy contributed the most for all diets, followed by meat for WDP, fish for SCP, and vegetables for MDP Water use: vegetables contributed the most for MDP, whereas vegetable oils contributed the most for SCP-FB and SCP-CS; dairy and vegetable oils made comparable contributions to WDP	MDP in Spain would reduce GHG (72%), agricultural land use (58%) and energy consumption (52%), and water consumption (33%). Adherence to a WDP would increase all of these between 12% and 72%. Adherence to an MDP would make a substantial contribution to increasing both food sustainability and the well-known benefits to public health.	Assumed recommendations from the MDP pyramid applied to the entire population rather than just the adult population. Methodologic limitations of consumption surveys and food balance sheets. Environmental impact limitations: representative food items used to estimate effects for food groups. Use of older data and data from other agroecological regions.

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Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost — Dietary pattern	Results: environment or cost — Food components	Summary of findings	Study limitations
Saxe, 2014 (34), modeling and data analysis, Netherlands	2 Dietary patterns: *1)* NND and *2)* average Dutch diet Scenario 1: baseline comparison of food components according to GWP and land use change Scenario 2: added environmental effects of international transport Scenario 3: added environmental effects of organic vs. conventional production	Both diets adhered to NND	LCA: production to distribution	GWP: NND vs. ADD: 30% decrease in GWP (CO_2eq) in scenario 1, 35% in scenario 2, and 32% in scenario 3 NND reduced environmental impact across 16 categories Cost: Socioeconomic savings for shift to NND was 26% of environmental cost of the ADD, equivalent to €266 (US$362.98) · person^{-1} · y^{-1} When the additional environmental cost of international transport was considered in scenario 2, savings rose to 32% of the environmental cost of the ADD; however, the higher cost of organic produce featured in the NND offsets this savings, reducing it to 5% of the environmental cost of the ADD in scenario 3, or €42 (US$57.31) · person^{-1} · y^{-1}	GWP: animal produce was responsible for 69% of environmental cost for ADD and 65% for NND; in scenario 2, animal produce was responsible for 63% for ADD and 64% for NDD; in scenario 3, animal produce was responsible for 59% for ADD and 68% for NND; the inclusion of land use change more than doubled the difference in GWP between the 2 diets	Reducing the content of meat and excluding most long-distance imports were of substantial environmental and socioeconomic advantage to the NND compared with the ADD. The study is novel in the inclusion of environmental effects beyond GHG and land use.	
Scarborough et al., 2012 (27), modeling and data analysis, United Kingdom	4 Dietary patterns: *1)* baseline (current United Kingdom dietary intake based on food purchase data from 2008); *2)* scenario 1 (50% reduction in meat and dairy, replaced by fruit, vegetables, and cereals); *3)* scenario 2 (75% reduction in red meat, replaced by pigs and poultry); and *3)* scenario 3 (50% reduction in pigs and poultry, replaced by fruit, vegetables, and cereals)	Total deaths delayed or averted per year compared with baseline diet (95% credible interval): scenario 1, 36,910 (30,192–43,592); scenario 2, 1999 (1739–2389); and scenario 3, 9297 (7288–11,301)	CCC diet scenarios: based on GHG and land use for agriculture both within and outside the United Kingdom, associated with food consumed in the United Kingdom	GHG emissions and land use: Diet 1: 19% decrease in GHG, 42% decrease in land use Diet 2: 9% decrease in GHG, 39% decrease in land use Diet 3: 3% decrease in GHG, 4% decrease in land use	Deaths delayed: for diet 1, reduction in meat and dairy, replaced by fruit, vegetables, and cereals, was the biggest contributor to deaths delayed; reductions in salt or changes in FAs made smaller contribution	Diet scenario 1 (50% reduction in meat and dairy, replaced by fruit, vegetables, and cereals) was the largest contributor to deaths delayed or averted and had the largest environmental impact.	Does not account for micronutrient deficiencies. Estimates of dietary quality from food purchase data are limited.
Scarborough et al., 2014 (14), cross-sectional	4 Dietary patterns (self-selected): *1)* meat eaters, *2)* fish eaters,	Previous analyses of same cohort showed lower BMI and fewer	LCA: production to distribution by using	GHG emissions, mean (95% CI) kg CO_2eq/d: High meat eaters (≥100 g/d):		Dietary GHG for self-selected meat eaters approximately double	Cross-sectional comparisons between

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Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost — Dietary pattern	Results: environment or cost — Food components	Summary of findings	Study limitations
study (EPIC-Oxford), United Kingdom	*3*) vegetarians, and *4*) vegans Food groups assessed by using an FFQ and recipes and adjusted to a 2000-kcal diet for comparison purposes	ischemic heart disease events in diet groups with lower intakes of animal products	Audsley (33) United Kingdom–specific data	7.19 (7.16, 7.22) Moderate meat eaters (50–99 g/d): 5.63 (5.61, 5.65) Low meat eaters (<50 g/d): 4.67 (4.65, 4.70) Fish eaters: 3.91 (3.88, 3.94) Vegetarians: 3.81 (3.79, 3.83) Vegans: 2.89 (2.83, 2.94)		emissions for vegans. It is likely that reductions in meat consumption would lead to reductions in dietary GHG.	dietary groups do not model actual dietary substitutions. Food waste not included. No weight adjustments-for raw vs. cooked foods. EPIC-Oxford cohort may not represent the United Kingdom population as a whole (healthier on average).
Soret et al., 2014 (35), prospective cohort (5.7 y) (AHS-2), USA	3 Dietary patterns: *1*) vegetarian, *2*) semivegetarian, and *3*) nonvegetarian Assessed by using a 210-item FFQ	All-cause mortality: Mortality rates: nonvegetarians, 6.66 deaths · 1000 persons^{-1} · y^{-1}; semivegetarians, 5.53 deaths · 1000 persons^{-1} · y^{-1}; vegetarians, 5.56 deaths · 1000 persons^{-1} · y^{-1} Compared with nonvegetarians: HR (95% CI) = 0.86 (0.77, 0.96) for semivegetarians and HR (95% CI) = 0.91 (0.83, 1.00) for vegetarians	LCA: production to distribution; attributional approach used to allocate emissions among the 210 foods	GHG emissions: Nonvegetarian: 3.05 kg CO_2eq/d Semivegetarian: 2.39 kg CO_2eq/d Vegetarian: 2.16 kg CO_2eq/d Compared with nonvegetarian, $P < 0.001$ for semivegetarian and nonvegetarian Compared with nonvegetarian, 22% decrease in GHG for semivegetarians; 29% decrease in GHG for vegetarians	GHG emissions: Overall pattern of GHG reflects underlying differential consumption of meat and plant foods Except for meat and plant foods, proportional contribution to GHG from dairy and eggs and other foods was comparable across the 3 diets	Moderate differences in caloric intake of meat products resulted in reductions in GHG and improved health outcomes, shown by mortality rates.	Inconsistent use of LCA boundaries across food groups. AHS-2 differs from US general population in terms of lifestyle characteristics.
Tilman and Clark, 2014 (36), modeling and data analysis, global	4 Dietary patterns: *1*) omnivorous, *2*) MDP, *3*) pescatarian, and *4*) vegetarian Data from 100 most populous nations for which annual data were available, 1961–2009	Chronic disease incidence and mortality: Compared with omnivorous diets, reduced type 2 diabetes by 16–41%, cancer by 7–13%, CHD mortality by 20–26%, and all-cause mortality by 0–18% for MDP,	LCA: food production (cradle-to-farm gate); data combined from 555 analyses on 82 crop and animal types	GHG emissions (2050): Reduce dietary GHG below 2050 projected levels (per capita): 30% MDP, 45% pescatarian diet, 55% vegetarian diet No net increase in food production GHG by 2050 if global diet becomes the average of MDP, pescatarian, and vegetarian diets; however, 32%	GHG emissions: Largest difference was ruminant meats (beef and lamb), GHG/g protein ~250 times legumes ($P < 0.0001$) Eggs, dairy, seafood, aquaculture, poultry, and pork had lower GHG per gram of protein than ruminant meats ($P < 0.0001$ for each comparison)	Analysis shows that there are plausible solutions to the diet-environment-health problem. Diets already chosen by many people could, if widely adopted, offer global environmental and public health benefits.	LCA studies limited by cradle-to-farm gate, excluding transport, waste, etc.

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TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost — Dietary pattern	Results: environment or cost — Food components	Summary of findings	Study limitations
		pescatarian, and vegetarian diets		increase in GHG by 2050 if dietary patterns continue income-dependent global trend Land use (2050): Omnivorous diets projected to require 370–740 million ha more crop land than MDP, pescatarian, and vegetarian diets			
van Dooren et al., 2014 (28), modeling and data analysis, Netherlands	6 Dietary patterns: *1)* ADD, *2)* DDG, *3)* semivegetarian, *4)* vegetarian, *5)* vegan, and *6)* MDP ADD based on Dutch National Food Consumption Survey 1998 DDG diet based on the 2006 DDG for adult women Vegetarian diet replaced meat with eggs, pulses and nuts, and meat substitutes Vegan diet substituted milk with calcium-enriched soy drinks and eggs with pulses Semivegetarian: average of DDG + vegetarian diets MDP based on the MDP pyramid: lower in meat and higher in fish, fruit, vegetables, plant oils	Health scores (based on WHO guidelines and Dutch Health Council indicators): ADD, 75; DDG, 105; semivegetarian, 103; vegetarian, 100; vegan, 118; MDP, 122 Omega-3 fish oils were lacking in the vegan and vegetarian diets Compared with the ADD, all other diets had substantial health benefits in terms of reducing chronic disease risk	LCA: scope not specified	Sustainability scores: ADD, 68; DDG, 90; semivegetarian, 98; vegetarian, 109; vegan, 130; MDP, 102 GHG index[2]: ADD, 80 (4.1 kg CO_2eq/d); DDG, 90 (3.6 kg CO_2eq/d); semivegetarian, 96 (3.4 kg CO_2eq/d); vegetarian, 102 (3.2 kg CO_2eq/d); vegan, 123 (2.7 kg CO_2eq/d); MDP, 96 (3.4 kg CO_2eq/d) Land use index[3]: ADD, 56 (5.34 $m^2 \cdot y/d$); DDG, 89 (3.3 $m^2 \cdot y/d$); semivegetarian, 100 (2.95 $m^2 \cdot y/d$); vegetarian: 115 (2.6 $m^2 \cdot y/d$); vegan, 137 (2.2 $m^2 \cdot y/d$); MDP, 107 (2.75 $m^2 \cdot y/d$) Sustainability score was the mean of GHG and land use score per diet	GHG emissions: Foods contributing most to GHG emissions in ADD: meat products (32%), dairy (19%), extras (snacks, sweets, and pastries; 13%), beverages (7%) Preparation and storage (17%) Land use: Foods contributing most to land use: meat (54%), extras (18%), dairy (11%), beverages (9%) GHG and land use: greatest reduction in GHG and land use from reducing consumption of meat, dairy products, extras, and beverages (alcoholic, juices, soft drinks, coffee, and tea), in that order	Compared with the ADD, a healthy diet in compliance with the DDG is projected to have a higher sustainability score; it also is projected to reduce GHG emissions by 11% and land use by 38%. The MDP, which had the highest health score, also had a higher sustainability score than the ADD. Diets with the optimal synergy between health and sustainability were oriented between a health focus and animal protein reduction (e.g., semivegetarian or pescovegetarian).	Health and sustainability scores could be improved by including water use and other environmental indicators.
Vieux et al., 2013 (15), cross-sectional study (INCA2), France	4 Dietary patterns: self-selected diets of French adults, classified as 4 patterns based on nutritional quality: high, intermediate+ (I+), intermediate– (I–), or low Based on indicators of	Highest nutrition quality diets have MAR above the median, MER and ED below the median	LCA: all stages	GHG: Without adjustment, diet-related GHGs were not significantly different between the 4 classes for men, but were significantly greater in the high class for women ($P < 0.0001$) After adjusting for diet weight, GHG was no longer	GHG: Ruminant meat associated with the greatest GHG GHG/100 g edible food part, g CO_2eq/d (in decreasing order): ruminant meat (1627); fish (612); pork, poultry, and eggs (610); mixed dishes (369); fats (342); dairy (283); sweets and	More nutrient-dense diets were associated with higher levels of GHG, although they contained more plant-based products. Food groups such as sweets and salted snacks were negatively	Food consumption data represented ~75% of total food and energy intake. GHG sole indicator of environmental

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TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost		Summary of findings	Study limitations
				Dietary pattern	Food components		
	nutritional quality: MAR, MER, and ED			significantly different across classes for either sex After adjusting for caloric intake, high-quality diets were associated with higher GHGs for both men and women (9% and 22%, respectively; $P < 0.0001$ for both)	salted snacks (197); starches (114); fruit and vegetables (114) GHG/100 kcal, g CO_2eq/d (in decreasing order): ruminant meat (857); fish (517); mixed dishes (312); pork, poultry, and eggs (308); fruit and vegetables (290); dairy (216); sweets and salted snacks (91); starches (61); fats (55)	associated with diet-related GHG, whereas fruit and vegetables were positively associated with diet-related GHG.	impact. Transport not included. Diet classification (according to nutrients) not previously published.
Wilson et al., 2013 (29), modeling and data analysis, NZ	16 Dietary patterns—4 groups (low cost, minimize GHG, "relatively healthy," and "more familiar meals") equivalent in energy and met dietary requirements: lowest cost (C1); low cost, including porridge and rotis (naan or flatbread) (C2); low cost, requiring minimal cooking skills (C3); low cost, with relatively high vegetable intake (C4); lowest GHG emissions, low cost (G1); same as G1, with higher cost per day (G2); same as G2, including porridge as standard meal (G3); same as G2 but vegan (G4); MDP; MDP-G; ASIAN; ASIAN-G; NZ-M; NZ-S; NZ-T; and NZ-P	All diets healthier than average NZ diet for preventing chronic disease Compared with typical NZ diet, the low-cost and low-GHG optimized diets improved CVD prevention Benefits include higher PUFA:SFA ratio, fewer SFAs from meat, and lower sodium and higher potassium intakes High-vegetable diets (C4, MDP, ASIAN) also provided benefits against CRC because of higher fiber	United Kingdom data on GHG profiles Farm-to-fork assessment	GHG emissions (kg CO_2eq/d): C1, 2.72; C2, 2.63; C3, 2.2; C4, 4.33; G1[3], 1.67; G1 with NZ, 1.39; G2[3], 1.31; G3[3], 1.56; G4[3], 1.9; ASIAN, 4.03; ASIAN-G[3], 3.29; MDP, 4.68; MDP-G[3], 2.17; NZ-M, 5.25; NZ-S, 4.54; NZ-T, 4.24; NZ-P, 5.98 Scenario G2 (low GHG, higher cost) associated with the lowest GHG Scenario G4 (low GHG, vegan) had slightly higher GHG than the other GHG-reduction scenarios "Healthier diet" scenarios, ASIAN-G (Asian diet, low GHG), and MDP-G (low GHG) associated with higher GHG than those to reduce GHG without following a healthier diet Diet costs (2 scenarios cost >NZ$7/d; US$5.85/d): Asian-G: NZ$8.3 (US$6.94); MDP-G: NZ$8.99 (US$7.52); MDP: simplified MDP cost NZ$5.64/d (US$4.72/d), despite including large amounts of fruit and vegetables and some fish; MDP-G: optimizing for GHG reduction increased cost to NZ$8.99/d (US$7.52/d); ASIAN: simplified Asian diet cost NZ$4.95/d (US$4.14/d); ASIAN-G: optimizing for GHG reduction increased cost to NZ$8.3/d (US $6.94); vegan (G4) more	GHG emissions—compared with scenario C1 (low cost), G1 with NZ GHG values [low cost, low GHG (NZ values)] resulted in: Increase in fruit and vegetables (except carrots) Increase in pulses, seeds, and nuts (except dried peas) Increase in oat and white flour, but decreases in wholemeal flour and pasta Increase in whole milk but decrease in milk powder Increase in vegetable oils, including margarine and peanut butter, but decreases in eggs and added sugar	All diets that aimed to minimize cost or GHG were both less expensive and healthier than the average NZ diet. Low-cost and low-GHG diets were complementary, with scenario G2 (low GHG, higher cost) being associated with the lowest GHG emissions. Increasing dietary variety and acceptability increased daily cost. "Healthier diets" that minimized GHG achieved smaller GHG reductions than scenarios that aimed to reduce GHG without following a healthier diet.	Food-specific GHG data from the United Kingdom rather than for NZ.

(*Continued*)

TABLE 1 (*Continued*)

Authors, year (ref), study design, location	Diet exposure (dietary pattern)	Health outcomes	LCA, other	Results: environment or cost — Dietary pattern	Results: environment or cost — Food components	Summary of findings	Study limitations
				expensive than the other low-GHG diets, at NZ$7/d (US$5.85/d) All scenarios cost less than half the estimated cost of average NZ diet			

[1] ADD, average Dutch diet; AHS-2, Adventist Health Study-2; ASIAN, Asian-style diet; ASIAN-G, Asian-style diet, but minimizing human-generated greenhouse gas emissions; CCC, Committee on Climate Change; CHD, coronary heart disease; CRC, colorectal cancer; CVD, cardiovascular disease; DACH, German Dietary Guidelines; DASH, Dietary Approaches to Stop Hypertension; DDG, Dutch Dietary Guidelines; ED, energy density; EPIC-NL, European Prospective Investigation into Cancer–Netherlands cohort; EPIC-Norfolk, European Prospective Investigation into Cancer–Norfolk cohort; FAOSTAT, Food and Agriculture Organization of the United Nations Statistics Division; GHG, human-generated greenhouse gas; GWP, global warming potential; INCA2, Individual and National Survey on Food Consumption; LCA, life cycle assessment; MAR, mean adequacy ratio; MDP, Mediterranean dietary pattern; MDP-G, MDP, but minimizing GHG; MER, mean excess ratio; MRIO, multiregional input-output; NND, New Nordic Diet; NORM-INT, average Italian diet, conventional farming; NR, not reported; NZ, New Zealand; NZ-M, more familiar New Zealand diet, main meal mince; NZ-P, more familiar New Zealand diet, Pacific theme; NZ-S, more familiar New Zealand diet, main meal sausages; NZ-T, more familiar New Zealand diet, main meal fish; OMNIV-BIO, omnivorous, organic farming; OMNIV-INT, omnivorous, conventional farming; PANDiet, probability of adequate nutrient intake; ref, reference; RPM, red and processed meats; SCP-CS, current Spanish with consumption surveys; SCP-FB, current Spanish with food balance; S&H, sustainable and healthy; UGB, less meat, more legumes and vegetables; VEGAN-BIO, vegan, organic farming; VEGAN-INT, vegan, conventional farming; VEGET-BIO, vegetarian, organic farming; VEGET-INT, vegetarian, conventional farming; WCRF, World Cancer Research Fund; WDP, Western dietary pattern; YLL, years of life lost; –, negative; +, positive.

[2] Estimated from the authors' Figure 2.

[3] These estimates refer to the "objective function value" of each scenario (i.e., the key value, such as cost or emissions, being minimized in the optimization process).

lacto-ovo vegetarian diet (24); the fossil fuel required to produce 1 kcal of protein was highest for beef and lamb. A study in New York State found that increasing the amount of meat in the diet increased per capita land requirements and supported fewer people, effectively lowering carrying capacity (23). In this model, however, modest amounts of beef and dairy could be accommodated; diets that included modest amounts of these foods could feed slightly more people than could vegetarian diets with higher quantities of fat. This was attributed to the use of land for grazing that could not otherwise be used for food crop production.

We identified several additional studies that examined vegetarian dietary patterns. Data from the Adventist Health Study 2 were used to characterize the differential environmental and health effects of 3 dietary patterns—vegetarian, semivegetarian, and nonvegetarian—that varied in animal and plant foods (35). Compared with the nonvegetarian diet, semivegetarian and vegetarian diets were projected to decrease GHG emissions and mortality rates. Tilman and Clark (36) compared pescatarian and vegetarian diets with an omnivorous diet. In their global assessment of 100 populous nations, they found that pescatarian and vegetarian diets decreased all-cause and ischemic heart disease mortality, as well as type 2 diabetes and cancer incidence, compared with an omnivorous diet. The same dietary pattern comparisons resulted in a projected reduction in GHG emissions and cropland use by 2050 for pescatarian and vegetarian diets compared with the omnivorous diet. For GHG emissions the largest difference (~250-fold) was between ruminant meats (beef and lamb) and legumes on a GHG emissions per gram of protein basis.

Other studies variously compared average national dietary patterns with vegetarian diets, dietary guidelines–related diets, and the MDP in selected countries (20, 22, 28). Overall, they estimated greater environmental benefits, including reduced projected GHG emissions and land use, resulting from vegan, lacto-ovo vegetarian, pescavegetarian, and dietary guidelines–related patterns and the MDP. These diets were healthier than the average diets consumed and most had high sustainability scores. According to van Dooren et al. (28), the consistent response measured across vegetarian, MDP, and dietary guidelines–related scores could be explained by a reduction in the consumption of meat, dairy, extras (e.g., snacks, sweets), and beverages, as well as a reduction in overall food consumption.

In all of the studies that assessed a dietary guidelines–related pattern (20, 22, 28), the patterns were projected to improve health benefits and environmental measures, including GHG emissions and land, water, and energy usage, compared with average consumption patterns. Studies that made additional comparisons found even greater environmental changes from lacto-ovo vegetarian and vegan diets (22, 28).

One study examined actual diets and evaluated their relation to GHG emissions (14). The study estimated the difference in dietary GHG emissions between self-selected meat eaters, fish eaters, vegetarians, and vegans in the EPIC-Oxford cohort in the United Kingdom. The highest GHG emissions were associated with the dietary pattern of individuals whose diet was high in meat (>100 g/d); GHG emissions decreased as meat consumption decreased from medium to low amounts (50–99 g/d to <50 g/d), and the lowest GHG emissions were observed for fish eaters, vegetarians, and vegans. Overall, GHG emissions associated with self-selected meat-eaters were ~2 times as high as those in vegans. This indicates that results from observational studies of self-selected diets are consistent with results from modeling analyses.

MDP and DASH dietary pattern. As previously indicated, the MDP was compared with average intake patterns of individual countries and with other vegetarian and dietary guidelines–related patterns in 2 different studies (26, 28). The MDP is a traditional dietary pattern characterized by abundant use of olive oil; high consumption of plant and plant-based foods (fruits, vegetables, legumes, cereals, nuts, and seeds); frequent but moderate intake of wine (especially red wine) with meals; moderate consumption of seafood, fermented dairy products (yogurt and cheese), poultry, and eggs; and lower intake of red and processed meats (RPM) and sweets (3). In both studies, adherence to the MDP, compared with usual intake, reduced the environmental footprint of the diet by decreasing GHG emissions, energy, land use for agriculture, and water. For the MDP in Spain, GHG emissions and land, water, and energy usage were decreased relative to the current Spanish diet. The health advantages of the MDP were based on previously documented public health benefits of the well-characterized Spanish MDP (40). Van Dooren et al. (28) found that the MDP had the highest health score of the multiple diets they compared in the Netherlands; however, the sustainability score, GHG emissions index, and land use index of the MDP were below those of vegan and vegetarian diet patterns, despite being above the Dutch dietary guidelines pattern and the average Dutch diet (ADD). Meat products in the Dutch diet had the greatest environmental impact in terms of GHG emissions and land use.

Tilman and Clark (36) compared the MDP with an omnivorous diet, in addition to the comparisons discussed above for pescatarian and vegetarian diets. Using population forecasts, they found that by 2050 the MDP may offer reduced coronary heart disease mortality, type 2 diabetes, and cancer incidence as well as reduced GHG emissions and cropland use, as compared with current trends in dietary pattern changes.

Another well-characterized dietary pattern, the DASH diet, was studied for relations to environmental outcomes. The DASH dietary pattern emphasizes the intake of vegetables, fruits, and whole grains; includes low-fat dairy products, poultry, fish, legumes, nontropical vegetable oils, and nuts; and limits the intake of sweets, sugar-sweetened beverages, and red meats. The health benefits of the DASH diet are well established: it has been shown to prevent or control hypertension and other chronic diseases. A cross-sectional study assessed adherence to a DASH diet in the EPIC-Norfolk cohort and its association with GHG emissions and diet costs (31). Greater adherence to a DASH dietary pattern was associated with lower GHG emissions in an across-quintiles comparison. GHG emissions were most strongly and positively associated with meat consumption and negatively associated with whole-grain consumption. Greater adherence to the DASH diet was associated with higher dietary costs, with the mean cost of diets in the top quintile of DASH scores being 18% higher than that of diets in the lowest quintile.

Diet scenarios. Another group of studies examined different diet scenarios that usually replaced animal-based foods with plant-based foods. Two studies focused on RPM. Aston et al. (16) evaluated a dietary pattern that was modeled on the average United Kingdom population in which the proportion of vegetarians in the survey was doubled and the remainder adopted a dietary pattern consistent with the lowest category of RPM consumers. They found that the low RPM or the vegetarian diet had a lower projected risk of diabetes and colorectal cancer, and the expected reduction in GHG emissions was ∼3% of the current total carbon dioxide emissions for agriculture. de Carvalho et al. (19) examined a high-RPM dietary pattern with diet quality assessed through use of the Brazilian Healthy Eating Index. They found that excessive meat intake was associated not only with poorer diet quality but also with increased projected GHG emissions (∼4% total carbon dioxide emitted by agriculture in Brazil). A third study (27) found that in the United Kingdom a diet with 50% reduced total meat and dairy replaced by fruit, vegetables, and cereals contributed the most to the estimated reduced risk of total mortality and had the greatest positive environmental impact.

Energy intake also was measured in studies. Pradhan et al. (25) examined 16 global dietary patterns grouped into 4 categories with per capita intake of low-, moderate-, high-, and very-high-calorie diets. They assessed the relation of these patterns to GHG emissions. Low-calorie diets had <2100 kcal/d per capita and were composed of >50% cereals or >70% starchy roots, cereals, and pulses. Animal products were a minor (<10% of dietary energy) component in this group. Moderate-, high-, and very-high-calorie diets had 2100–2399, 2400–2800, and >2800 kcal/d per capita, respectively. Very-high-calorie diets contained large amounts of meat and alcoholic beverages. Overall, the very-high-calorie diets that are common in the developed world exhibited high total per capita carbon dioxide emissions as a result of the high intake of animal products, whereas the low-calorie diets had the lowest total per capita carbon dioxide emissions.

Vieux et al. (15) examined dietary patterns with different indicators of nutritional quality and found that despite containing large amounts of plant foods, not all diets of the highest nutritional quality were those with the lowest GHG emissions. For this study, 4 dietary patterns were identified through use of nutrient-based indicators: 1 high-, 2 intermediate-, and 1 low-quality diet. The high-quality diet had higher GHG emissions than the low-quality diet. A higher consumption of starches, sweets, and salted snacks was associated with lower GHG emissions, and an increased intake of fruit and vegetables was associated with increased

GHG emissions; however, the strongest positive association with GHG emissions was for the ruminant meat group.

Biesbroek et al. (30) examined the ADD in the EPIC-NL cohort and modeled a meat-substitution scenario, with one-third of the usual meat intake substituted with other foods. In a 16-y follow-up, modeled substitutions of 35 g meat/d with vegetables; fruit, nuts, and seeds; pasta, rice, and couscous; or fish were associated with increased survival rates and reduced GHG emissions and land use. A second epidemiologic modeling study designed the New Nordic Diet (NND) to be both healthy and sustainable; it contained 35% less meat than the ADD (34). Meat in the NND was substituted with whole-grain products, nuts, fruits, and vegetables. Overall, the NND reduced the environmental impact relative to the ADD in all 16 impact categories. The socioeconomic savings related to this diet shift was 32% of the overall environmental cost of the ADD.

Sustainable diets and related costs. Three studies in the original SR (18, 21, 29) and 2 studies in the update (13, 33) examined sustainable diets and related costs. Macdiarmid et al. (21) examined a "sustainable with acceptability constraints" diet that included 52 foods, which was projected to reduce dietary GHG emissions by 36%. This diet included dairy and meat but less of these foods than in the average United Kingdom diet. The cost of the sustainable plus "acceptability" diet was comparable to that of the average United Kingdom diet, showing that a sustainable diet that meets dietary requirements and projected lower GHG emissions can be achieved without eliminating meat or dairy products completely and without increasing the cost to the consumer. Wilson et al. (29) modeled several dietary patterns focused on decreased GHG emissions or costs, as well as vegetarian/vegan patterns, MDP, and Asian dietary patterns. They found that all diets that minimized costs or GHG emissions were both less expensive and healthier than the average New Zealand diet; however, healthier diets such as the MDP and Asian dietary pattern achieved smaller GHG-emission reductions than patterns modeled to reduce GHG emissions alone. When these patterns were optimized to reduce GHG emissions, they became more expensive than the simplified versions. The vegan low GHG-emissions pattern also was more expensive than other low GHG-emission patterns.

Another approach to examining food costs was food basket modeling, a common approach for assessing food costs and availability. In Australia, Barosh et al. (18) compared a typical food basket with a sustainable and healthy (S&H) food basket. The typical food basket was based on average weekly food purchases of a reference household, and the S&H basket added adherence to Australian dietary guidelines and environmental impact. The cost of the S&H basket was more than the typical basket; the most economically disadvantaged individuals spent 30% more for the S&H basket. In this analysis, the most economically disadvantaged groups at both neighborhood and household levels experienced the greatest difficulty in accessing an affordable S&H basket.

A cross-sectional study from the Individual and National Food Consumption Survey assessed self-selected diets that were culturally acceptable in France (13). Results showed that 23% of men and 20% of women consumed a "more sustainable" diet. This diet had an above average diet quality score and below average GHG emissions, costs, and energy density and energy content compared with the average French diet. Overall, a 20% reduction in diet-related GHG emissions while maintaining high nutritional quality was possible at no extra cost by reducing energy intake and energy density and increasing the share of plant-based products.

Another study from the United Kingdom modeled diet scenarios that improved health and reduced GHG emissions based on compliance with WHO dietary recommendations and GHG emissions targets (33). Adherence to the WHO dietary recommendations alone resulted in a 17% decrease in GHG emissions compared with the average British diet. Diet scenarios that were modeled on further GHG emissions reductions were projected to reduce the incidence of mortality, coronary heart disease, stroke, some cancers, and type 2 diabetes. A >40% GHG-emissions reduction, however, was predicted to alter acceptability of the diet and reduce some health benefits. Overall, the combined benefits of moderate diet modifications were achieved by reducing consumption of animal products and processed foods and increasing consumption of cereals, vegetables, and fruits.

Conclusions

The 2015 DGAC concluded "Consistent evidence indicates that, in general, a dietary pattern that is higher in plant-based foods, such as vegetables, fruits, whole grains, legumes, nuts, and seeds, and lower in animal-based foods is more health promoting and is associated with lesser environmental impact (GHG and energy, land, and water use) than is the current average US diet. A diet more environmentally sustainable than the average US diet can be achieved without excluding any food groups. The evidence consists primarily of LCA modeling studies or land use studies from highly developed countries, including the United States" (3). Our update further supports and strengthens the original conclusions.

Overall, the studies in this updated SR were consistent with the original review in showing that higher consumption of animal-based foods was associated with higher estimated environmental impact, whereas increased consumption of plant-based foods was associated with an estimated lower environmental impact. Assessment of individual foods within these broader categories showed that meat—sometimes specified as RPM or ruminant meat (beef and lamb)—was consistently identified as the single food with the greatest impact on the environment, most often in terms of GHG emissions and/or land use.

The evidence demonstrates that health-promoting dietary patterns also improve environmental sustainability indicators; dietary patterns that adhered to dietary guidelines (in total, not in part) were more sustainable than the population's current average amount of dietary pattern intake. Well-characterized dietary patterns with known health benefits, such as the MDP and DASH diets, also were shown to be more environmentally sustainable than average consumption patterns. Taken together, the studies agreed on the environmental impact of different dietary patterns, despite varied methods of assessment and life cycle stages included. There was limited and inconsistent evidence as to whether sustainable diets were more or less expensive than average diets. This is an important question to address in future studies.

We recognize the strength and limitations of these studies. The main strengths include state-of-the-art LCA, comprehensive assessment of health outcomes (including both morbidity and mortality) in the dietary patterns considered, examination of multiple dietary patterns under different scenarios, and reproducibility and/or consistency of findings across different populations. The potential limitations are that most of the studies are cross-sectional rather than longitudinal, the environmental impact is based on modeling analysis, most of the studies were conducted in Europe, and the measurements of dietary patterns were not entirely consistent across different studies.

It also should be kept in mind that these studies, in general, use averaged production practice data to determine the GHG or land use impact of particular food items. Within each, however, there is a wide range of actual practices; for example, flood furrow compared with trickle irrigation. The combination of irrigation-efficiency improvements, irrigation timing, and controlled deficits could result in a 17% savings of water in California (41). Producing in different places, even in the off-season, could demonstrate improvements in GHG emissions release potential (42). The production of commodity crops such as corn and soybean exhibit a wide range of net GHG emissions potential, depending on production practices (43). There is the possibility that different ruminant production strategies will exhibit marked differences in net GHG emissions, depending on the carbon-sequestration potential—an area requiring a great deal of additional research. In other words, although the literature presented in this SR is clear on the broad impacts of dietary patterns and environmental attributes, there is much that can be done to refine these to improve the relation between a diet that promotes human health and improves the state of our global ecosystem.

This SR update provides a robust body of evidence that confirmed the results and conclusions of the original 2015 DGAC SR. The fact that >50% more studies (8) were identified in the 1-y period after the original SR that spanned more than a decade demonstrates the scientific attention that this area of research is receiving. All of the additional studies were consistent with the original SR and provided more evidence to support the findings of the DGAC that dietary guidelines–related diets, the MDP, the DASH diet, and vegetarian diets (with variations) were associated with both improved health and better environmental outcomes. The body of evidence was expanded in terms of the number and type of studies (more observational studies, including a 16-y prospective cohort study), improved consistency of results across health and environmental outcomes, and increased generalizability to the US population. As new evidence has emerged, the original SR has been strengthened and does not require any modification or alteration to the original conclusions and implications. The insights from our updated SR show the potential for efficacy of food policies focused on dietary patterns in contributing significantly to not only improved public health but also improved environmental outcomes and the potential for food security for future generations. It is important to note that food sustainability was not included in the final 2015–2020 Dietary Guidelines for Americans (44). We expect future research in this topic area to inform the 2020 DGAC and dietary guidelines process.

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