REVIEW

Systematic Review of Dietary Patterns and Sustainability in the United States

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ABSTRACT

Improving awareness and accessibility of healthy diets are key challenges for health professionals and policymakers alike. While the US government has been assessing and encouraging nutritious diets via the Dietary Guidelines for Americans (DGA) since 1980, the long-term sustainability, and thus availability, of those diets has received less attention. The 2015 Dietary Guidelines Advisory Committee (DGAC) examined the evidence on sustainable diets for the first time, but this topic was not included within the scope of work for the 2020 DGAC. The objective of this study was to systematically review the evidence on US dietary patterns and sustainability outcomes published from 2015 to 2019 replicating the 2015 DGAC methodology. The 22 studies meeting inclusion criteria reveal a rapid expansion of research on US dietary patterns and sustainability, including 8 studies comparing the sustainability of DGA-compliant dietary patterns with current US diets. Our results challenge prior findings that diets adhering to national dietary guidelines are more sustainable than current average diets and indicate that the Healthy US-style dietary pattern recommended by the DGA may lead to similar or increased greenhouse gas emissions, energy use, and water use compared with the current US diet. However, consistent with previous research, studies meeting inclusion criteria generally support the conclusion that, among healthy dietary patterns, those higher in plant-based foods and lower in animal-based foods would be beneficial for environmental sustainability. Additional research is needed to further evaluate ways to improve food system sustainability through both dietary shifts and agricultural practices in the United States. *Adv Nutr* 2020;0:1–16.

Keywords: Dietary Guidelines for Americans, sustainability, sustainable diets, dietary patterns, dietary recommendations, sustainable food systems, public health, environmental health

Introduction

Nutrition and public health professionals increasingly recognize that a systems approach is needed to address the complex and interconnected challenges facing population health (1). Two of the leading threats to global health are climate change and noncommunicable diseases, both of which are inextricably linked to diet (2). Dietary patterns directly drive health outcomes via the relation between nutrition and chronic disease, and indirectly influence health by way of the social, economic, and environmental consequences of food production systems (3).

The environmental impacts of current food production and consumption patterns are substantial, threatening the future availability of natural resources such as land, healthy soil, and clean water. Agriculture has been estimated to account for 70% of global freshwater use and ∼37% of the world's land (4, 5). In total, the agricultural sector has accounted for an estimated 11% of global greenhouse gas emissions (GHGs) during the last decade, while the broader food system, including manufacturing agricultural inputs, food processing, and transportation, has accounted for up to an estimated 37% of global emissions (6).

In the United States, agricultural production systems and consumption of foods from the global food system contribute

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Supplemental Material are available from the "Supplementary Material" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/advances/.
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Abbreviations used: DGA, Dietary Guidelines for Americans; DGAC, Dietary Guidelines Advisory Committee; EIO-LCA, Economic Input-Output Life Cycle Assessment; GHG, greenhouse gas emission; HEI, Healthy Eating Index; LCA, Life Cycle Assessment; PLCA, Process Based Life Cycle Assessment.

significantly to resource use and environmental degradation, while providing suboptimal benefits for population health (7–10). The Western diet is characterized by high intakes of animal foods (e.g., beef, pork, poultry, and dairy), processed foods, refined sugars, and fats and low intakes of whole grains, fruits, and vegetables and is associated with increased morbidity and mortality worldwide. Much of the food frequently consumed in the United States and in other countries is produced in ways that rely heavily on nonrenewable inputs and unsustainable practices (11–14).

Shifting to more sustainable dietary patterns is a key strategy for meeting present and future food needs (15–17). As defined by the FAO, sustainable diets are those "having low environmental impact and contributing to food and nutrition security and healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems; culturally acceptable; accessible; economically fair and affordable; nutritionally adequate, safe, and healthy; and optimize natural and human resources" (18). The sustainability of diets is influenced by both the foods comprising the diet as well as the ways in which those foods are produced, including levels of loss and waste across the supply chain. Identifying, improving, and promoting dietary patterns that can optimize ecological, economic, environmental, health, and social benefits in various settings is an important area of research and policymaking.

In the United States, one critical lever to shift diets is the Dietary Guidelines for Americans (DGA), a set of recommendations issued by federal agencies every 5 y based on an expert review of current science by a Dietary Guidelines Advisory Committee (DGAC). In response to growing evidence that diets impact natural resources and climate, the 2015 DGAC examined the scientific evidence linking dietary patterns to sustainability outcomes for the first time, but the conclusions and recommendations of the committee were omitted from the 2015–2020 DGA (19, 20). Further, the 2020 DGAC is not expected to reevaluate or address this topic (21). However, there is a pressing need for evidence-based policymaking and promotion of dietary patterns that are mutually beneficial for long-term health and sustainability goals (22).

The purpose of this study was to systematically review the peer-reviewed scientific literature examining dietary patterns and sustainability published between July 2015 and September 2019, focusing on the United States. To our knowledge, this is the first systematic review to focus on US dietary patterns and food sustainability, filling a crucial gap in the literature that can inform the development of evidence-based US food and nutrition policy.

Methods

We conducted a systematic review in response to the question addressed by the 2015 DGAC (20) and subsequently by Nelson et al. (23): What is the relation between population-level dietary patterns and food sustainability and related food security? To promote continuity between the aforementioned systematic reviews, we closely replicated the analytical framework and methodology those studies applied (see **Figure 1**), with minor modifications as the documented search methods did not consistently replicate the original search results and search term changes had occurred since the original review (see **Table 1** and **Supplemental Material**).

In brief, we searched for papers published from July 2015 to September 2019 using the BIOSIS, CAB, Cochrane, Embase, Food Science and Technology Abstracts (FSTA), and PubMed databases. Inclusion criteria identified original studies published in peer-reviewed, English-language journals. Study populations in included papers were from high or very high Human Development Index countries and considered healthy or at elevated risk of chronic disease and comprised individuals ages ≥2 y. Study designs were limited to randomized and nonrandomized controlled trials, prospective cohort studies, cross-sectional studies, case-control studies, and modeling studies that had ≥10 subjects per treatment arm and a follow-up rate of ≥80%. Systematic reviews, meta-analyses, and narrative reviews were excluded. Last, studies were required to describe a diet exposure, associated health outcomes, and sustainability or food security outcomes. Studies evaluating medical treatment and low-calorie diets for weight loss were excluded. All studies were independently evaluated by ≥2 reviewers according to these criteria using DistillerSR (Evidence Partners) data extraction software to achieve agreement on study inclusion. An additional search ("hand search") was then conducted through a review of the citations in included articles (**Figure 2**). Articles identified through the hand search were also evaluated against inclusion criteria by ≥2 reviewers.

Studies focusing on US-specific diets and outcomes, including global studies reporting results specific to the United States, were then identified among the included articles, as the primary focus of this study was to review and synthesize existing evidence on US dietary patterns. A data extraction grid was used to compile information on dietary patterns, methods, sustainability outcomes, and funding for all US studies meeting the inclusion criteria. Study quality and risk of bias were assessed using a critical appraisal checklist developed for the 2015 DGAC (Supplemental Material).

For the purpose of interpreting results of studies comparing environmental impacts of ≥2 dietary patterns, in the absence of comprehensive uncertainty analyses, we applied default estimates based on expert judgment used in life-cycle assessment to determine when differences are significant. Similar to previous studies, we assumed a 10% minimum difference in GHGs and energy use and a 30% minimum difference in land use, water use, and water pollution (eutrophication) to be significant (24, 25).

Results

Characteristics of studies meeting the inclusion criteria

Twenty-two studies assessing the sustainability of US dietary patterns met the inclusion criteria for the current review (8,

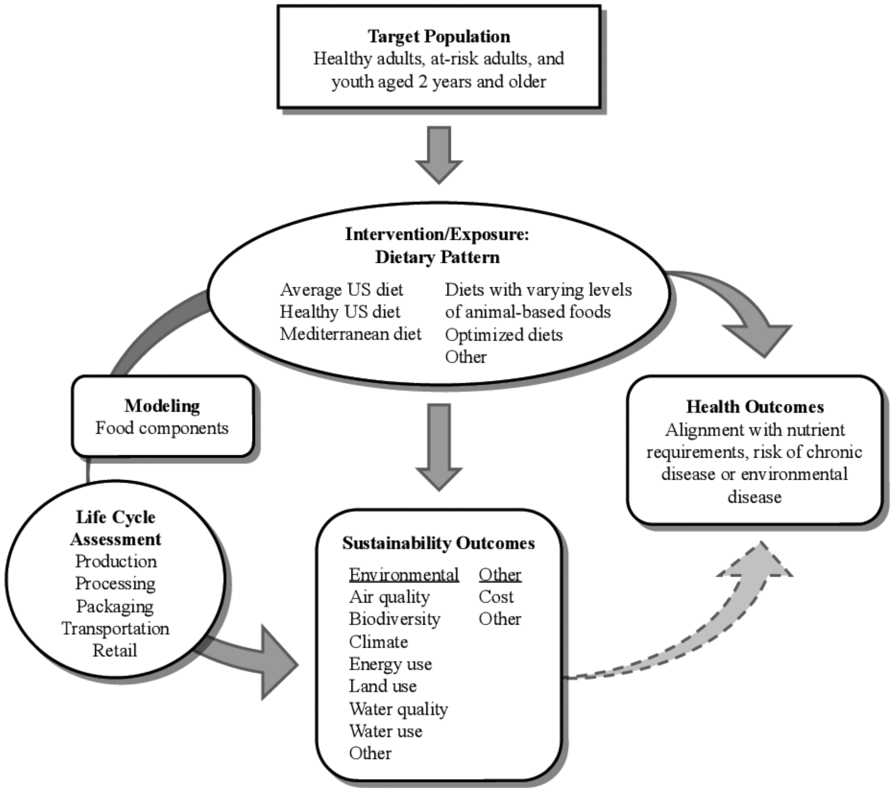

FIGURE 1 Analytical framework. Adapted from reference 23 with permission.

9, 24, 26–44). By comparison, Nelson et al. (23) identified 4 US studies published between January 2000 and July 2015. Seventy-three additional international and global studies, including 10 global studies not reporting US-specific results, also met the inclusion criteria, compared with 19 identified by Nelson et al. (23). Further, the rate of publication of such studies increased substantially between 2003 and 2016 and has remained high since 2016 (**Figure 3**). The remainder of reported results focus on US-specific studies only.

The studies varied in the diets and health outcomes they considered (Table 1). Of the 22 studies included in the current review, 16 (73%) examined both observed (i.e., based on empirical data and representative of actual population-level diets) and modeled diets (i.e., consistent with evidence-based recommendations or hypothetical scenarios). Three studies (14%) examined only observed dietary patterns, and three examined only modeled dietary patterns. While most studies assumed that health improvements would be achieved through alignment with evidence-based dietary recommendations, two studies (8%) explicitly evaluated health outcomes associated with shifting dietary patterns (32, 42). All studies used national data on food consumed, purchased or available for consumption from federal datasets and surveys to estimate diets and were thus externally valid to the U.S. population.

The types of impacts assessed in the included studies varied (Table 1). Most studies (64%) assessed GHGs attributed to dietary patterns, while fewer assessed land use (36%), water use (36%), energy use (18%), or water quality (14%) impacts. Four studies (18%) evaluated fertilizer use or nitrogen losses and 4 (18%) reported findings on food waste. Thirty-six percent of studies examined $\geq$3 environmental impacts, while the remainder addressed only 1 or 2. In addition to environmental impacts, 5 studies (23%) included aspects of the social or economic sustainability of diets by evaluating food accessibility, cost, or affordability.

Methods for assessing environmental impacts of dietary patterns varied across studies. However, Life Cycle Assessment (LCA) was the most common. LCA is a quantitative modeling approach to estimate cumulative environmental impacts (e.g., water use and global warming potential) along a product's supply chain. The system boundaries of LCAs in the reviewed studies vary, but all began with the "cradle" or raw material extraction for agricultural inputs. Thirteen studies (59%) used either Economic Input-Output Life Cycle Assessment (EIO-LCA) or a compilation of food-specific Process Based Life Cycle Assessment (PLCA) studies. Studies using EIO-LCA estimated environmental impacts of dietary patterns by merging environmental impacts and economic flows of food and agricultural industries producing food for purchase or consumption in the United States. System boundaries for these studies were cradle-to-retail stage of the food supply chain, where retail included restaurants, grocery stores, or other places where consumers

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

		Dietary pattern(s)		Methods and outcome(s)				
Study (ref)	Year	Observed (source)	Theoretical (source)	LCA system boundary	Waste included	Outcome(s)	Findings[2] (excerpt from abstract)	Funding
Behrens et al.[3,4] (8)	2017	Diets of 37 nations, including the USA (FAOSTAT)	37 dietary patterns: nationally recommended diet of 37 nations, including USA (DGA)	Cradle to retail	Yes	Climate, land use, water quality	Eutrophication impacts of US diet is nearly double the average in upper-middle income nations and high-income nations, and more than quadruple the average in lower-middle income nations. US GHGs are 3.4 kg CO2eq person/d, which is 40% higher than the average of all high-income nations.	None
Birney et al.[4] (26)	2017	US diet (ERS LAFA)	2 dietary patterns: model diet meeting food group calorie recommendations (DGA), and model diet also minimizing food loss and waste reduction goals (EPA)	Varies	Yes	Climate, energy use, land use, waste, water use, other (fertilizer use)	A shift in consumption towards a healthier diet could increase food related energy use by 34%, increase blue water consumption 15%, decrease green water use 7%, increase GHGs from food production 7%, increase GHGs from landfills 34%, and decrease land use by 19%.	Corporate; government/public university
Blackstone et al. (24)	2018	N/A	3 dietary patterns: Healthy US, Healthy Mediterranean, and Healthy Vegetarian diets (DGA)	Cradle to farm gate or processor gate (excluding packaging)	No	Air quality, climate, land use, water pollution, water use	The US and MED patterns had similar impacts, except for freshwater eutrophication, which was 31% lower in the US pattern. For 5 of the 6 impacts, the VEG pattern had 42–84% lower burdens than both the US and MED patterns.	Private university
Blas et al. (27)	2016	N/A	2 dietary patterns: Mediterranean (MDF) and American recommended diet (DGA)	Farm to farm gate	N/A	Water use	The recommended American diet had a 29% higher water footprint compared to the Mediterranean diet, regardless of products' origin.	Nonprofit/philanthropic

(*Continued*)

TABLE 1 (*Continued*)

Study (ref)	Year	Dietary pattern(s): Observed (source)	Dietary pattern(s): Theoretical (source)	Methods and outcome(s): LCA system boundary	Methods and outcome(s): Waste included	Methods and outcome(s): Outcome(s)	Findings[2] (excerpt from abstract)	Funding
Boehm et al. (28)	2019	US diet (FoodAPS)	N/A	Cradle to retail	Yes	Climate	Average GHGs were significantly lower and HEI-2010 scores were significantly higher for households spending the least on red meat as a share of total food spending.	Nonprofit/philanthropic; private university
Conrad et al. (29)	2018	US diet (NHANES)	N/A	N/A	N/A	Waste, other (food loss and associated water, fertilizer, and pesticide waste)	US consumers wasted 422 g of food per person daily, with 30 million acres of cropland used to produce this food every year. Higher quality diets were associated with greater amounts of food waste and greater amounts of wasted irrigation water and pesticides, but less cropland waste.	Government/public university
Eshel et al. (30)	2016	US diet (ERS LAFA)	1 dietary pattern: model diet meeting nutrient constraints and minimizing land use, GHG emission, and reactive nitrogen use	N/A	N/A	Climate, land use, other (nitrogen loss)	Protein-equivalent plant alternatives require on average only 10% of land, 4% of GHGs, and 6% of reactive nitrogen compared to what the replaced beef diet requires.	Unknown
Gephart et al. (31)	2016	N/A	5 dietary patterns: model diets meeting nutrient and serving constraints (DGA) while minimizing environmental impacts	Cradle to farm gate or primary processing	Uncertain	Climate, land use, water quality, water use, other (nitrogen loss)	Diets for the minimized footprints tend to be similar for the four footprints (GHGs, nitrogen release, water use, and land use), suggesting there are generally synergies, rather than tradeoffs, among low-footprint diets.	Government/public university

(*Continued*)

TABLE 1 (*Continued*)

Study (ref)	Year	Dietary pattern(s): Observed (source)	Dietary pattern(s): Theoretical (source)	Methods and outcome(s): LCA system boundary	Methods and outcome(s): Waste included	Methods and outcome(s): Outcome(s)	Findings[2] (excerpt from abstract)	Funding
Hallstrom et al. (32)	2017	US diet (ERS LAFA)	3 dietary patterns: diets based on recommended US food patterns (DGA) with reductions in processed and red meat	Cradle to retail	Yes	Climate	Adoption of healthier diets reduced the relative risk of coronary heart disease, colorectal cancer, and type 2 diabetes by 20–45%, US health care costs by \$77–\$93 billion per year, and direct GHGs by 222–826 kg CO_2e per capita per year (69–84 kg from the health care system, and 153–742 kg from the food system).	None
Hitaj et al. (33)	2019	US diet (NHANES)	4 dietary patterns: diets meeting calorie, nutrient, and food pattern recommendations (DGA) with constraints on meat intake, cost, and energy	Cradle to retail	Yes	Climate, cost, energy use	An omnivore diet that meets the DGAs while constraining cost leaves food system GHGs unchanged relative to the current baseline diet, while a DGA compliant vegetarian and omnivore diet that minimizes energy consumption reduce GHGs by 32% and 22%, respectively.	Government/public university
Kim et al.[3,4] (34)	2019	Baseline diet of 140 countries, including the USA (FAOSTAT); average diet of OECD countries; adjusted baseline diet	9 dietary patterns: diets meeting recommendations (WHO, AICR) and containing varying levels of animal products (meatless day, low red meat, no dairy, no red meat, pescatarian, lacto-ovo vegetarian, 2/3 vegan, low food chain, vegan)	Farm to farm gate	Yes	Climate, water use	In 95% of countries, diets that only included animal products for one meal per day were less GHG-intensive than lacto-ovo vegetarian diets in part due to the GHG-intensity of dairy foods. The US has the fourth highest per-capita GHG footprint globally.	Nonprofit/philanthropic
Mekonnen and Fulton (35)	2018	US diet (ERS LAFA)	5 dietary patterns: Healthy US, Healthy US at 2000 kcal, Healthy Mediterranean, Healthy Vegetarian, and Vegan diets (DGA)	Farm to farm gate	No	Waste, water use	A shift to a healthy diet will not always lead to a reduced water footprint. Dietary shifts to vegan and vegetarian diets provide larger reductions in the consumptive water footprint. Reducing food loss and waste produced the largest potential water footprint reduction.	Government/public university

(*Continued*)

TABLE 1 (*Continued*)

Study (ref)	Year	Dietary pattern(s): Observed (source)	Dietary pattern(s): Theoretical (source)	Methods and outcome(s): LCA system boundary	Methods and outcome(s): Waste included	Methods and outcome(s): Outcome(s)	Findings[2] (excerpt from abstract)	Funding
Mulik and O'Hara (36)	2015	US diet (ERS LAFA)	7 dietary patterns: diets meeting recommendations for fruits and vegetables and varying levels of dairy and protein (DGA, Harvard University Healthy Eating Plate)	N/A	N/A	Cost, land use	Fruit and vegetable acreage would increase by 5.4 million acres in the US if Americans were to meet recommendations for fruits and vegetables. US cereal grain acreage would decrease under both animal protein consumption scenarios and decrease under 1 of the 2 dairy product consumption scenarios we consider.	None
Peters et al. (37)	2016	US diet (ERS LAFA) and energy-balanced positive control diet	8 dietary patterns: diets meeting food group recommendations (DGA) with varied levels of animal products (5 omnivore, 2 vegetarian, 1 vegan)	N/A	N/A	Land use	Annual per capita land requirements ranged from 0.13 to 1.08 ha per person per year across the 10 diet scenarios. Carrying capacity was generally higher for scenarios with less meat and highest for the lacto-vegetarian diet.	Nonprofit/philanthropic
Rehkamp and Canning[4] (38)	2017	US diet (NHANES)	2 dietary patterns: 1 meeting caloric, food group, and nutrient targets (DGA) and minimizing changes from US diet (realistic healthy diet); 1 meeting only caloric and nutrient targets and minimizing energy use (energy-efficient healthy diet)	Cradle to retail	Yes	Cost, energy use	In both healthy diets analyzed, diet-related energy use fell compared to the energy use associated with current US diets and the average wholesale cost of the diets was the same or less than that of the current US diet.	None
Rehkamp and Canning (39)	2018	US diet (NHANES)	4 dietary patterns: 1 Healthy US diet and 1 Healthy Vegetarian (lacto-ovo-vegetarian) diet minimizing change from the current US diet; 1 Healthy US diet and 1 Healthy Vegetarian diet minimizing water use (DGA). All diets have equal or lower cost than the current average US diet.	Cradle to retail	Yes	Cost, water use	Making minimal changes from current US consumption to a healthy omnivore or vegetarian diet, blue water use increases by 16%, but the omnivore and vegetarian diets reduce embodied blue water by 63% and 66%, respectively, when the objective is to minimize water use.	None

(*Continued*)

TABLE 1 (*Continued*)

Study (ref)	Year	Dietary pattern(s)		Methods and outcome(s)			Findings[2] (excerpt from abstract)	Funding
		Observed (source)	Theoretical (source)	LCA system boundary	Waste included	Outcome(s)		
Ritchie et al.[3] (9)	2018	N/A	8 dietary patterns: diets meeting recommendations in the USA (DGA), Australia, Canada, Germany, China, India (vegetarian and omnivore); diet meeting WHO recommendations; 2050 diet based on projected demand ("business as usual")	Cradle to farm gate	Uncertain	Climate	A wide disparity in the emissions intensity of recommended healthy diets exists, ranging from 687 kg CO2e per capita per year for the guideline Indian diet to 1579 kg CO2e per capita per year in the US. The majority of current national guidelines are highly inconsistent with a 1.5°C target.	Nonprofit/philanthropic
Rose et al. (40)	2019	US diet (NHANES)	N/A	Cradle to farm gate or primary processing	Uncertain	Climate	Diets in the bottom quintile of US dietary GHGs accounted for one-fifth the total emissions of those in the top quintile, yet had significantly higher HEI scores by 2.3 ± 0.7 points on a 100-point scale.	Nonprofit/philanthropic
Shepon et al. (41)	2018	US diet (ERS LAFA)	1 dietary pattern: model diet substituting nutritionally equivalent plant-based foods for beef, pork, dairy, poultry, and eggs	N/A	N/A	Land use, waste	Plant-based replacements for each of the major animal categories in the United States (beef, pork, dairy, poultry, and eggs) can produce 2-fold to 20-fold more nutritionally similar food per unit of cropland.	None
Stylianou et al. (42)	2016	US diet (ERS LAFA)	3 dietary patterns: US diet plus 1 serving of fluid milk; isocaloric US diet with 1 additional serving of fluid milk; isocaloric US diet substituting fluid milk for sugar-sweetened beverages	Cradle to farm gate or primary processing	Uncertain	Air quality, climate	Findings suggest that adding 1 serving of milk to the current average diet could result in health benefits for American adults, assuming that existing foods associated with substantial health benefits are not substituted, such as fruits and vegetables.	Corporate

(*Continued*)

TABLE 1 (*Continued*)

		Dietary pattern(s)		Methods and outcome(s)				
Study (ref)	Year	Observed (source)	Theoretical (source)	LCA system boundary	Waste included	Outcome(s)	Findings[2] (excerpt from abstract)	Funding
Tom et al. (43)	2016	US diet (ERS LAFA)	3 dietary patterns: US diet meeting calorie recommendations; isocaloric US diet meeting recommended food pattern (DGA); US diet meeting calorie and food pattern recommendations (DGA)	Farm to farm gate	Uncertain	Climate, energy use, water use	Shifting from the current US diet to recommended calorie levels decreases energy use, blue water footprint, and GHGs by around 9%, while shifting to isocaloric recommended food patterns increases energy use by 43%, blue water footprint by 16%, and GHGs by 11%.	Nonprofit/philanthropic; private university
White and Hall (44)	2017	US diet (ERS LAFA)	4 dietary patterns: model diets optimized to meet nutrient needs (DGA, WHO) with least cost, with and without animal products, and with and without imported foods	N/A	N/A	Climate, cost	The modeled removal of animals from the US agricultural system resulted in predictions of greater total production of food (23%), increased deficiency in essential nutrients, and a 28% decrease in agricultural GHGs.	None

[1] AICR, American Institute for Cancer Research; CO2e, carbon dioxide equivalents; DGA, Dietary Guidelines for Americans; EPA, Environmental Protection Agency; ERS, Economic Research Service; FAOSTAT, Food and Agriculture Organization of the United Nations Statistical Databases; FoodAPS, National Household Food Acquisition and Purchase Survey; GHG, greenhouse gas emission; HEI, Healthy Eating Index; LAFA, Loss-Adjusted Food Availability Data Series; MDF, Mediterranean Diet Foundation; MED, Mediterranean; N/A, not applicable; OECD, Organization for Economic Cooperation and Development; VEG, vegetarian.
[2] Unless otherwise noted, all findings are quotes or adapted quotes from paper abstracts.
[3] Indicates global study reporting US-specific outcomes.
[4] Findings column contains text not included in the paper abstract.

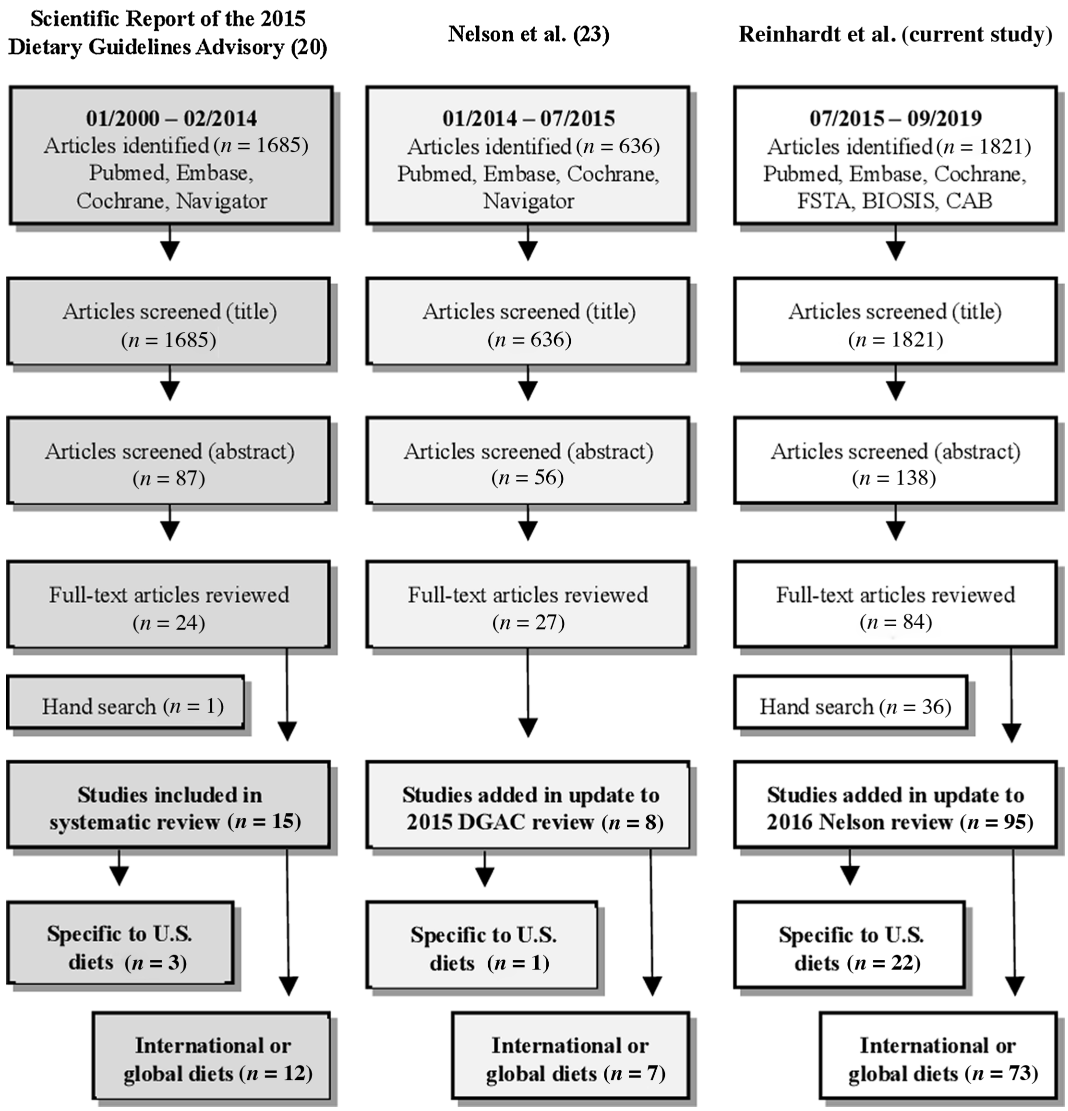

FIGURE 2 Literature search and selection flowchart. Navigator encompasses FSTA, BIOSIS Previews, and CAB Abstracts databases (EBSCO Information Services). Studies labeled "Specific to U.S. diets" include global studies reporting US-specific results. FSTA, Food Science and Technology Abstracts; DGAC, Dietary Guidelines Advisory Committee. Adapted from reference 23 with permission.

purchase food (8, 28, 32, 33, 39). System boundaries for PLCA studies were typically cradle-to-farm-gate, although some included primary processing of agricultural products (cradle-to-processor-gate) (24, 31, 40, 42, 43). Nine of the 22 studies (41%) captured environmental impacts associated with food waste or loss occurring at some point along the food supply chain, although only 4 reported findings specific to food waste and its impacts (8, 26, 28, 32–34, 38, 39). While 14 studies included climate impacts via GHGs as an environmental impact category, only 2 accounted for GHGs from land-use change (e.g., plant or soil carbon change from conversion of land from one use to another within a supply chain) (24, 34). Studies not using compiled PLCA data or conducting EIO-LCA relied on previously published databases quantifying environmental impacts of agriculture and livestock production (37, 45–50).

Of the 22 included US studies, the majority (86%) were published in interdisciplinary journals, most of which have an environmental science or policy focus (64% of all studies). Four were published in public health or nutrition journals and 2 were published in economics or applied economics journals. Seven of the studies were funded by nonprofit and philanthropic organizations, 5 by government or public universities, 3 by private universities, and 2 by corporations or trade associations; 2 of these had multiple funding sources. Seven studies reported no funding source and 1 study did not report funding information.

As determined by the critical appraisal checklist, the quality of included studies was high, with studies receiving scores of 8–11 out of 12, with a mean score of 10.5 and a mode of 11. See the Supplemental Material for a detailed discussion of the quality and bias of the included studies.

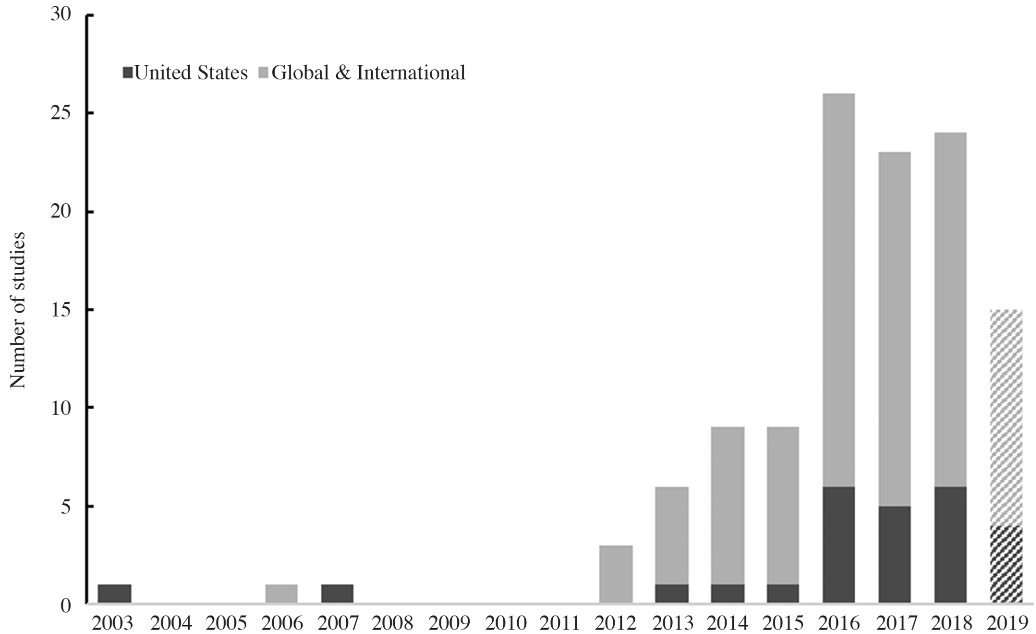

FIGURE 3 Number of studies on dietary patterns and sustainability published annually, 2003–2019. Includes studies from the 2016 DGAC report (51–54), Nelson et al. (23), and the current systematic review. US studies include global studies reporting outcomes specific to the United States. International studies are those reporting results from a high or very high Human Development Index country other than the United States. Global studies are those reporting results from multiple countries. For the purposes of this figure, global studies include only those that do not report outcomes specific to the United States. Results represent studies published through September 2019 only, as indicated by the hatched bar. DGAC, Dietary Guidelines Advisory Committee.

Sustainability of diets compliant with the DGA

Fourteen of the 22 studies (8, 24, 26–29, 33, 35, 37–40, 43) evaluated the environmental sustainability of diets in compliance with the DGA, including the Healthy US-style (omnivore), Healthy Mediterranean-style, Healthy Vegetarian, and Vegan dietary patterns. Eight of these studies compared the environmental impacts of current US diets with the Healthy US-style pattern, one of which also considered the Healthy Mediterranean-style diet, and 4 of which also considered Healthy Vegetarian or Vegan diets (**Table 2**). While most of these studies included multiple variations of DGA-compliant model diets, only isocaloric shifts (shifts in diet composition that maintain constant caloric intake) are described in Table 2 and synthesized below, with the exception of Birney et al. (26). Additionally, 2 studies compared only multiple DGA-compliant patterns (24, 27), and 3 studies assessed the alignment of the current average US diet with the Healthy US-style pattern as measured by the Healthy Eating Index (HEI) (28, 29, 40).

Healthy US-style pattern.

Studies modeling shifts from the current average US diet to the Healthy US-style pattern consistently found that the latter would require greater intakes of fruits, vegetables, and dairy and lesser intakes of meat and poultry, as well as oils, fats, and sugars. Changes in intake of seafood, grains, and nuts varied (8, 26, 33, 35, 37–39, 43).

Three of 4 studies comparing GHGs of current average US diets and the Healthy US-style pattern (26, 33, 43) found that adoption of the Healthy US-style diet would result in similar or increased GHGs (9–12% increase), one of which accounted for additional GHGs resulting from greater landfill waste associated with dietary shifts (26). However, a global study by Behrens et al. (8) found that isocaloric adherence to a Healthy US-style pattern was associated with a 23% reduction in GHGs. This discrepancy may be partially explained by differences in the construction of the current and recommended model diets, system boundaries, and calculations of associated food loss and waste (8).

Of the 3 studies evaluating energy use of current and recommended diets, 2 found that the Healthy US-style pattern was associated with between 34% and 43% greater energy use, due in part to increased intakes of fruits and vegetables (26, 43). Meanwhile, Rehkamp and Canning (38) found that a diet designed to meet Healthy US-style nutrient and food pattern requirements while also minimizing differences from the current average US diet would result in similar energy use (38).

Four studies found that a Healthy US-style diet was associated with similar or increased use of blue water (surface and groundwater in streams, lakes, and aquifers), driven partly by increases in dairy, fruits, and vegetables. Tom et al. (43), Rehkamp and Canning (39), and Birney et al. (26) found similar blue water use (15–16% increase) compared with the current average US diet, while Mekonnen and Fulton

TABLE 2 Environmental impacts of DGA-compliant dietary patterns compared with current average US dietary patterns[1]

	Water use (blue/green)[2]	Climate	Land use	Energy use	Fertilizer use	Water pollution
Healthy US (omnivore)						
Behrens et al. (8)	—	↓	↓	—	—	↓
Birney et al. (26)	(↑)/(↓)	(↑)	(↓)	↑	↑	—
Hitaj et al.[3] (33)	—	↑	—	—	—	—
Mekonnen and Fulton (35)	↑/(↑)	—	—	—	—	—
Peters et al. (37)	—	—	(↓)	—	—	—
Rehkamp and Canning[3] (38)	—	—	—	(↓)	—	—
Rehkamp and Canning[3,4] (39)	(↑)/—	—	—	—	—	—
Tom et al. (43)	(↑)/—	↑	—	↑	—	—
Mediterranean						
Mekonnen and Fulton (35)	↑/(↑)	—	—	—	—	—
Vegetarian						
Hitaj et al.[3,4] (33)		↓	—	—	—	—
Mekonnen and Fulton (35)	↑/(↓)	—	—	—	—	—
Peters et al. (37)	—	—	↓	—	—	—
Rehkamp and Canning[3,4] (39)	(↑)/—	—	—	—	—	—
Vegan						
Mekonnen and Fulton (35)	(↑)/↓	—	—	—	—	—
Peters et al. (37)	—	—	↓	—	—	—

[1] Upward (downward) pointing arrows indicate that the DGA-compliant diet has higher (lower) environmental impact compared with current average US diet. All comparisons are isocaloric (equivalent in total calories) with the exception of comparisons made by Birney et al. (26), which include the impact of reducing calorie intake to recommended levels. (↓) or (↑) indicates a nonsignificant difference of <10% (energy use, GHGs) or <30% (land use, water use, water pollution) between the DGA-compliant dietary pattern and current average US diet, based on default estimates used for life-cycle assessments. DGA, Dietary Guidelines for Americans; GHG, greenhouse gas emission.
[2] Blue water is surface and groundwater in streams, lakes, and aquifers; green water is rainwater and soil moisture.
[3] Model DGA-compliant diet minimizes changes from current average (baseline) diet.
[4] Model DGA-compliant diet maintains or reduces costs relative to current average (baseline) diet.

(35) reported a 35% increase in blue water use. Mekonnen and Fulton (35) and Birney et al. (26) found no difference in use of green water (rainwater and soil moisture) (4–7% decrease). Three studies evaluating land use reported similar or decreased land use under the Healthy US-style pattern (10–30% decrease) (8, 26, 37).

Healthy Mediterranean-style pattern.
Mekonnen and Fulton (35) found a 40% increase in blue water use associated with a Mediterranean-style pattern compared with the current average US diet. Their findings are consistent with those of Blackstone et al. (24), who found comparable water use between the Healthy US-style and Mediterranean-style patterns, in addition to comparable air quality, climate, and land use impacts. Blas and colleagues (27) reported that the Healthy US-style pattern had a larger water footprint compared with a Mediterranean diet as constructed by the Mediterranean Diet Foundation in Spain; this inconsistency may be partially explained by differences in the construction of this diet and the DGA-compliant Mediterranean-style diet.

Healthy Vegetarian and Vegan patterns.
Two studies comparing Healthy Vegetarian and Vegan patterns with current average US diets or other DGA-compliant diets reported lower GHGs and land use. Hitaj et al. (33) found that a cost-constrained Healthy Vegetarian diet could reduce GHGs by 32% relative to the current average US diet, and Peters et al. (37) found that land requirements for Healthy Vegetarian and Vegan diets were, respectively, 86% and 87% lower than omnivorous diets, although vegan diets demonstrated a lower carrying capacity than vegetarian diets. These findings are consistent with Blackstone et al. (24), who reported lower air quality, climate, land use, and water quality impacts associated with DGA-compliant Healthy Vegetarian diets than either Healthy US-style or Mediterranean-style diets.

With respect to water use, Rehkamp and Canning (39) found similar blue water footprints among the current average US diet and Healthy Vegetarian and Healthy US-style diets designed to minimize changes from the current diet and maintain or reduce diet costs, consistent with results from Blackstone et al. (24). Mekonnen and Fulton (35) reported a 31% increase in blue water use under a Healthy Vegetarian diet and similar water use (28% increase) under a Vegan diet; however, green water use remained similar or decreased, with similar water use (26% decrease) under a Healthy Vegetarian and a 44% decrease under a Vegan diet.

Dietary accordance with the HEI.
Three studies evaluated US dietary alignment with healthy US dietary patterns as measured by HEI scores (28, 29, 40). Rose et al. (40) found that food patterns with lesser climate impacts also had higher overall diet quality; diets in the bottom quintile of dietary GHGs had HEI scores that were 2.3 points higher on a scale of 100. They found that diets with low GHGs contained less meat, dairy, and solid fats and more poultry, plant protein foods, oils,

whole and refined grains, and added sugars. Boehm et al. (28) also found that average GHGs were significantly lower and HEI scores were significantly higher among households spending the least on red meat as a share of total food spending. However, Conrad et al. (29) found that higher diet quality was also associated with higher levels of food waste and associated wasted irrigation water and pesticides.

Diets containing varying levels of animal-based foods

Six studies evaluated diets with varying levels of animal-based products (30, 32, 34, 41, 42, 44). Hallstrom et al. (32) found that diets low in red and processed meat and designed to minimize chronic disease risk could reduce the risk of coronary heart disease, colorectal cancer, and type 2 diabetes by 20–45% and decreasing health care costs by up to $93 billion per year, although generating only marginal reductions in food and health-care system GHGs. Kim et al. (34) found that the US population, with the fourth highest per-capita GHG footprint globally, could reduce its GHG footprint by adhering to any of 9 modeled plant-based diets. Vegan and low-food-chain diets yielded the lowest footprint; however, in most countries, lacto-ovo-vegetarian diets produced GHGs greater than diets that included animal products for only one meal a day, largely due to the impacts of dairy. Three other studies identified the potential for GHG reductions through reduced consumption of red meat and other animal protein foods (including beef, pork, poultry, and eggs), although one of these (44) concluded that complete removal of animal products from the US agricultural system would result in deficits of certain fatty acids, vitamins, and minerals (30, 41, 44). Stylianou and colleagues (42) evaluated human health impacts resulting from diet-driven changes in GHGs and particulate matter, finding that increased milk consumption may have net health benefits for the US population, assuming milk is not replacing healthy foods such as fruits and vegetables.

Other modeled or optimized diets

Three other studies estimated environmental impacts of modeled diets but did not make comparisons to current diets. Ritchie et al. (9) found that the Healthy US-style diet was associated with higher GHGs than recommended diets of Australia, Canada, China, Germany, and India (vegetarian and nonvegetarian), as well as the WHO Healthy Diet. Gephart et al. (31) found that diets optimized to meet nutrient constraints while minimizing environmental impacts reduced GHGs, nitrogen release, land use, and water use, indicating that there may be synergies among low-footprint diets. Finally, Mulik and O'Hara (36) found that US fruit and vegetable acreage would increase by 5.4 million acres, while US cereal grain acreage would decrease, under multiple scenarios in which the US population met dietary recommendations for fruits and vegetables, dairy, and protein.

Discussion

This is the first systematic review of research pertaining specifically to US dietary patterns and sustainability outcomes. A key strength of this study is that it replicated the methodology employed by the 2015 DGAC in its review of evidence on dietary patterns and sustainability outcomes in the global context. At that time, there was not sufficient evidence to warrant a US-specific review, but research on this topic has since expanded. Two primary conclusions were drawn from our review of included US studies: *1*) recent US research does not support prior findings that diets adhering to national dietary guidelines are necessarily more sustainable than current average diets and *2*) research continues to support previous findings that, among healthy dietary patterns, those higher in plant-based foods and lower in animal-based foods benefit environmental sustainability. We graded these conclusions as "strong," based on the systematic review grading criteria used by the 2015 DGAC (see Supplemental Material). Despite some inconsistencies and general limitations of this field of research, the included studies provide a new body of high-quality evidence using nationally representative data sources that points to a common pathway for improving health and food security for current and future generations and highlights key opportunities for future research. Here we summarize these conclusions and describe future research needs.

Recent US research does not support prior findings that diets adhering to national dietary guidelines are necessarily more sustainable than current average diets

Nelson et al. (23) concluded that "dietary patterns that adhered to dietary guidelines (in total, not in part), were more sustainable than the population's current average dietary pattern intake." This conclusion was based on available evidence from primarily non-US studies. Yet, our findings indicate that the Healthy US-style dietary pattern, as currently recommended by the DGA, generates GHGs and energy and water use at levels higher than or indistinguishable from the current average US diet. (Studies reporting $<$10% difference in GHGs or 30% difference in energy or water use between dietary patterns, and whose actual differences are therefore uncertain, are indicated in Table 2.)

Limited research on other DGA-compliant dietary patterns also suggests that the environmental impacts of the Mediterranean-style diet are comparable to the US Healthy-style diet across multiple environmental indicators. Nevertheless, additional US-based research is needed to evaluate the environmental impacts of DGA-compliant diets, including the influence of cost constraints and minimized differences from current diets.

Research continues to support previous findings that, among healthy dietary patterns, those higher in plant-based foods and lower in animal-based foods benefit environmental sustainability

Studies comparing Healthy Vegetarian diets with other DGA-compliant patterns reported environmental benefits such as

reduced energy and land use and air and water pollution (24, 33, 37). Among all included studies, those finding that lower consumption of animal-based foods generated lesser environmental impacts attributed these effects primarily to changes in the type and amount of meat (e.g., beef, pork, lamb) or dairy in the diet. (8, 9, 24, 26–28, 30–34, 37, 38, 40, 41, 35). Broadly, our findings are consistent with other recent reviews of dietary sustainability (12, 20, 55–57). However, more research may be required to better quantify the water use associated with higher proportions of plant-based foods such as fruits, vegetables, and nuts in the diet, and evaluate potential tradeoffs with other dietary shifts (24, 39).

Recommendations for future research

The 2015 DGAC recommended more in-depth analyses of US domestic dietary patterns. While the studies meeting inclusion criteria demonstrate significant growth in this domain, continued research should remain a priority. Furthermore, other research recommendations made by the 2015 DGAC have not yet been fully realized. These include the following: research assessing how to communicate and motivate the population to eat sustainable diets, assessment of whether there are systems in place to ensure that sustainable diets are affordable and available to the entire US population, and analysis of the sustainability of fish and seafood consumption from different production systems (20).

Finally, recent studies and meta-analyses have provided strong evidence indicating that specific dietary inter-food-group substitutions have the potential to reduce the environmental burdens of the food system more than improvements in agricultural practices, especially for animal-based foods (12, 58, 59). However, dietary shifts and improvements in agricultural production are both essential (15). Additional research examining US dietary patterns is needed to evaluate the linkages and tradeoffs between diet shifts and agricultural production shifts to meet targets for achieving food system sustainability. In particular, more agroecological and systems-based research is needed to identify and improve the sustainability and resilience of both crop and livestock systems, and such research should be incorporated into studies evaluating the health and sustainability of dietary patterns (60, 61).

There are several acknowledged shortcomings in the methods and scope of the included studies. First, a majority of the studies meeting the inclusion criteria only evaluated GHGs as the primary indicator of environmental sustainability. Fewer studies focused on other environmental impacts such as energy use, land use, water use, and water quality, or evaluated multiple environmental impacts simultaneously to understand synergies and tradeoffs among them. Second, sustainability is a multidimensional concept that encompasses not only environmental considerations but also social and economic conditions; although these dimensions introduce additional complexity and difficulty into such analyses, they are essential to understanding the societal implications of proposed dietary shifts. Third, more studies should identify the health and environmental impacts of incremental dietary change, as opposed to presenting wholesale comparisons between current and model diets. Although such comparisons are useful for demonstrating maximum possible benefits, they are limited in their practical application, particularly as they pertain to policies aiming to produce optimal impacts with finite resources across diverse systems.

Finally, there is a need to more consistently account for the role of food waste across the supply chain in research pertaining to dietary sustainability. This generates wide variability in the estimated impacts of dietary patterns, depending on the extent that study methodologies account for food waste at various stages of the supply chain (62).

Limitations

To maintain consistency and continuity between prior systematic reviews on this topic, we closely followed methodology developed by the 2015 DGAC. However, search terms and bias assessment tools appropriate for use 5 y ago require adjustments to return the most relevant results today. We managed this limitation, in part, by adjusting search methodology and completing a thorough hand search. The high proportion of total studies identified through the hand search—approximately one-third—indicates that even the revised search terms did not capture the full breadth of relevant research. This may, in part, reflect a lag effect in databases developing and implementing relevant terms and categories for new research areas. Furthermore, the critical appraisal checklist applied to assess study quality and bias could be modified to align with current best practices (25, 63).

There are also limitations to the body of research from which the review draws. Although LCAs are a common and useful tool for assessing environmental impacts of dietary choices, there are challenges and limitations to their application. High variability in LCA outcomes can result from mutable parameters such as system boundaries and choice of functional units, as well as the ability to account for uncertainty, and few LCAs consider land use change (55). Data used in such models overwhelmingly represent prevailing methods of food production and do not frequently take into account diverse practices, such as those informed by agroecology, that may improve environmental outcomes. Identified gaps in the life-cycle data availability of certain foods, including fish and meat alternatives, prohibit a greater insight into their potential role in sustainable diets (24).

Conclusions

This review adds to a growing body of evidence that dietary guidance can be leveraged to deliver better health through nutrition, as well as through long-term preservation and regeneration of natural resources and climate adaptation and mitigation. This area of research and policy has garnered interest and support from leading national public health and nutrition institutions, and countries around the world are increasingly issuing recommendations pertaining to

planetary health within national dietary guidance (51–54). Dietary shifts implemented alongside evidence-based transitions to more sustainable and ecologically informed agricultural practices, reductions in waste across the supply chain, and equitable redistribution of power and resources will also be critical to meeting key benchmarks for human development (64). To these ends, we suggest that the US government actively engage in the review, evaluation, and synthesis of research on US dietary patterns to inform policy solutions addressing 2 of the greatest threats to population health: noncommunicable disease and climate change (2). Similarly, the federal agencies overseeing nutrition and environmental research should prioritize funding for this work. Continued expansion and evolution of this body of research are critical to identifying incongruities or tradeoffs between healthy and sustainable diets, and the economic and social implications thereof, and to developing meaningful dietary recommendations that will meet the needs of both current and future populations.

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