Conrad et al. Nutrition Journal (2024) 23:159
https://doi.org/10.1186/s12937-024-01050-z

Nutrition Journal

RESEARCH

Open Access

Greater adherence to the Mediterranean diet pattern in the United States is associated with sustainability trade-offs

Zach Conrad[1,2*], Madison Korol[2], Chloe DiStaso[2] and Songze Wu[2]

Abstract

Background The Mediterranean diet pattern has been consistently associated with health benefits but less is known about the association with environmental and economic sustainability in the United States (US). This information is needed to support sustainable policy agendas and provide consumers with evidence-based information needed to make informed food choices. This study fills this research gap by evaluating the environmental sustainability and diet cost associated with adherence to the Mediterranean diet pattern in the US.

Methods Dietary data from the National Health and Nutrition Examination Survey (2011–2018, $n = 17,079$) were merged with data on environmental impacts (greenhouse gas emissions, cumulative energy demand, water scarcity footprint), agricultural resource demand (land, fertilizer nutrients, and pesticides), and food prices from multiple publicly available databases. The Mediterranean Diet Score was used to evaluate adherence to the Mediterranean diet pattern. Multivariable linear regression models were used to evaluate the association between adherence to the Mediterranean diet pattern and environmental impacts, agricultural resource demand, and diet cost. Sensitivity analyses were used to evaluate adjustment of loss and waste and food-away-from-home prices.

Results Greater adherence to the Mediterranean diet pattern was associated with lower greenhouse gas emissions ($p < 0.001$), land use ($p < 0.001$), fertilizer nutrient use ($p < 0.001$), and pesticide use ($p < 0.001$), higher water scarcity footprint ($p < 0.001$) and diet cost ($p < 0.001$), and no change in cumulative energy demand ($p = 0.147$). These changes were driven primarily by reduced intake of animal-sourced foods such as beef dishes, meat sandwiches, and dairy, as well as decreased intake of refined carbohydrate foods such as refined grain dishes and soft drinks.

Conclusions This nationally representative study demonstrates that greater adherence to the Mediterranean diet pattern is associated with sustainability trade-offs. These findings have implications for the development of sustainable dietary guidelines and clinical practice guidelines that can be used to inform consumer food choices.

Keywords Mediterranean, Diet quality, Sustainability, NHANES, Greenhouse gas emissions

*Correspondence:
Zach Conrad
zsconrad@wm.edu
[1] Department of Kinesiology, William & Mary, Williamsburg, VA 23185, USA
[2] Global Research Institute, William & Mary, Williamsburg, VA 23185, USA

Introduction

The Mediterranean diet pattern is characterized by high amounts of fruit, vegetables, whole grains, legumes, nuts and seeds, and seafood, and is rich in monounsaturated fats from vegetable oils [1]. Greater adherence to the Mediterranean diet pattern has been consistently associated with reduced risk for adverse cardiometabolic outcomes including metabolic syndrome, diabetes, stroke, and heart disease, as well as reduced risk of mortality from these conditions [2–8].

Given these health benefits, the Mediterranean diet is recommended by the American Heart Association [8, 9] and emphasized in the Dietary Guidelines for Americans (DGA) [10]. However, there is increasing recognition that food choices have sustainability impacts that extend beyond their health effects [11]. In 2022 the Biden-Harris administration in the United States (US) released the National Strategy on Hunger, Nutrition, and Health, which calls for increased investment in research that identifies healthy diet patterns that are also environmentally friendly and affordable, and greater support for research that evaluates the relationships between these sustainability domains [12]. At the same time, many consumers report making food choices based on multiple sustainability attributes, including nutritional value, environmental sustainability, and affordability [13].

Investigating the relationship of diet patterns to health outcomes, environmental impacts, and affordability can help identify sustainability trade-offs. Identifying these trade-offs is needed to support sustainable policy agendas and provide consumers with evidence-based information to make informed food choices. Globally, prior research has demonstrated that healthy diet patterns can lead to some environmental benefits while worsening others, with wide variation by national income level (e.g., lower greenhouse gas emissions, but greater use of cropland, water, and phosphorus fertilizer in low-income countries) [14]. Additional research has shown that recommended diet patterns have become more affordable but have continued to threaten environmental sustainability [15]. In the US, higher diet quality has been associated with lower greenhouse gas emissions (GHGE) for some (low grain, restricted carbohydrate, and low fat) but not all (plant-based and time restricted) popular diet patterns, and is often associated with higher costs (plant-based, low grain, restricted carbohydrate and low fat, but not time restricted) [16]. Other research has demonstrated that healthier diets can reduce some but not all environmental impacts and may increase diet costs for some lower income groups [17]. Food choices that emphasize certain sustainability criteria, such as geographic origin, seasonality, and reduced packaging may also increase diet costs [18]. Higher scores on the Healthy Eating Index (HEI)−2015 have also been associated with greater use of agricultural resources like pesticides and irrigation water, but no association was observed when using the Alternative Healthy Eating Index-2010 to measure diet quality [19].

The sustainability impacts of the Mediterranean diet pattern have been well documented in the international literature, which generally shows that greater adherence is associated with lower environmental impacts and diet cost [20–24]. However, less is known about the sustainability impacts of the Mediterranean diet pattern in the US context. A comparison of modeled diet patterns showed that, compared to other diet patterns, the Mediterranean diet was associated with greater water use, water eutrophication, airborne particulate matter [25], and GHGE [26]. To our knowledge, only one study has evaluated the sustainability impact of the Mediterranean diet in the US using individual-level dietary data, which showed that greater adherence was associated with lower GHGE [27]. No studies have evaluated the association between adherence to the Mediterranean diet pattern with other environmental outcomes (such as cumulative energy demand, water scarcity footprint, and use of agricultural land, fertilizer nutrients, and pesticides) and diet cost using individual-level dietary data in a nationally representative US sample, which limits a discussion of potential synergies and trade-offs. This information is needed to support sustainable policy agendas and inform consumer decision-making around sustainable food choices.

To fill this gap, the objectives of the present study are to 1) evaluate the association between adherence to the Mediterranean diet pattern and multiple environmental impacts (GHGE, cumulative energy demand, and water scarcity footprint), agricultural resource requirements (land, fertilizer nutrients, and pesticides), and diet costs, 2) evaluate the contribution of food categories to each of these sustainability outcomes, and 3) discuss the implications of these findings from a health information perspective.

Methods

Dietary data

The National Health and Nutrition Examination Survey (NHANES; 2011–2018) provided data on individual-level dietary intake and sociodemographic characteristics of US participants [28]. NHANES collects data from approximately 5,000 non-institutionalized participants per year using a multi-stage sampling design. Data are collected continuously and released in two-year cycles. Dietary data from the first of two 24-h recalls were used because this measures per capita intake, which is the recommended approach when describing dietary intakes at the group level and comparing intakes between groups [29]. Foods reported consumed by participants were categorized into using data on food composition from the Food and Nutrient Database for Dietary Studies (FNDDS) [30] and Food Patterns Equivalents Database (FPED; Supplemental Table 1) [31]. Participants provided written informed consent and the study protocol was approved by Institutional Review Board at the

National Center for Health Statistics. The present study is a secondary data analysis and was exempted from human studies ethical review by the Institutional Review Board at William & Mary.

Mediterranean diet score

Adherence to the Mediterranean diet pattern was measured using the Mediterranean Diet Score which includes ten components [32]. All components are scored as 0 or 1, with 1 representing more favorable intake. Favorable intakes are assessed using the following cutoffs: greater than the sex-specific median for vegetables, fruit, legumes, nuts and seeds, whole grains, seafood, and ratio of monounsaturated fatty acids to saturated fatty acids; less than the sex-specific median for dairy and red and processed meat; and 10–20 g/d of alcohol for men and 1.4–5.7 g/d of alcohol for women. Scores for each component are summed with a maximum total score of 10.

Environmental impacts: greenhouse gas emissions, cumulative energy demand, and water scarcity footprint

Data on GHGE, cumulative energy demand (CED), and water scarcity footprint (WSF; representing surface and groundwater, also known as blue water) for each food reported consumed by NHANES participants were acquired from the database of Food Impacts on the Environment for Linking to Diets (dataFIELD) [33, 34]. dataFIELD was created using a systematic review of food environmental life cycle assessments (LCA) published from 2005–2016 ($n=321$), representing most regions of the world, with the majority from Europe [35]. System boundaries varied across studies: nearly all accounted for agricultural production, 51% accounted for post-farmgate processing, 19% accounted for distribution and retail, and 6% accounted for the consumer-level impacts. All functional units were standardized to kg of edible food. Impact data on 1,645 combinations of food types and production scenarios were collated, averaged across studies, and matched to commodities in the Food Commodity Intake Database (FCID). FCID was established by the US Environmental Protection Agency (US EPA) and provides the mass quantity of approximately 500 ingredients in each NHANES food [36]. FCID has not been updated since 2010 so others have developed methods for updating these data to align with more recent NHANES surveys, [37] which were used in the present study. Briefly, two investigators independently established novel data linkages between FCID recipes from 2001–2010 to NHANES mixed dishes from 2011–2018, a third investigator adjudicated discrepancies, and a fourth investigator audited all linkages. Impact data were summed across all foods consumed by each NHANES participant to estimate individual-level impacts.

Agricultural resource requirements: land, fertilizer nutrients, and pesticides

The Foodprint model was used to evaluate the agricultural resource requirements (land, fertilizer nutrients, and pesticides) of individual-level diet patterns [38]. Foodprint is a biophysical simulation model that uses data on individual-level dietary intake of 22 food groups (grains, dark green vegetables, red and orange vegetables, legumes, starchy vegetables, other vegetables, fluid milk and yogurt, cheese and other dairy, soy milk, nuts, tofu, beef, pork, chicken, turkey, eggs, seafood, plant oils, dairy fats, lard and tallow, and sweeteners), and transforms their mass quantity as they move backwards through the food system from consumer foods to processed products to agricultural commodities to the agricultural resources needed to produce these commodities. Embedded data and calculations account for population size, international food trade, loss and waste, food composition, food processing conversions, livestock feed requirements, crop and livestock yields, availability of agricultural land, suitability of agricultural land for food production, multi-use crops (i.e., crops that are used to produce multiple products from equivalent mass), multi-use cropland (i.e., cropland used to produce multiple crops during different parts of the year), and application rates for fertilizer nutrients, pesticides, and irrigation water. Additional details are available elsewhere [38].

Diet cost

The Purchase-to-Plate Price Tool (PPPT) provided information on national average prices for each NHANES food (2011–2018) [39]. PPPT was developed by the US Department of Agriculture's Economic Research Service (USDA ERS) using transaction data from retail checkout scanners acquired from InfoScan, which represents nearly 50% of all retail food sales in the US [40]. USDA ERS staff use machine learning to match these data with NHANES foods and adjust the prices for losses and waste to reflect the cost associated with the consumed portion only [41].

Participants in NHANES provide information on whether they consumed each food at home (FAH) or food away from home (FAFH). Consumers typically face higher prices for FAFH (e.g., restaurants) than FAH (e.g., grocery stores), and other data show that FAFH represents approximately 50% of consumer food expenditures at the population level [42]. However, there are no publicly available data on national average FAFH prices for NHANES foods because PPPT assigns FAH prices to all foods regardless of the location of purchase or consumption, which can lead to underestimated diet costs at the individual level. Therefore, the present study derived FAFH prices using a methodology previously demonstrated [43–45] and described below.

Data from the National Household Food Acquisition and Purchase Survey (FoodAPS) [46] were used to derive coefficients that converted FAH prices (from PPPT) to FAFH prices for each of the FAFH reported consumed by NHANES participants. FoodAPS collected data from US households on the price of FAH and FAFH from receipts and scanned barcodes from April 2012 through January 2013 using a multi-stage sampling design [46]. Coefficients that represent the ratio of FAFH-to-FAH prices for each food group (meat, poultry, seafood, eggs, dairy, fats and oils, fruits and vegetables, sweets, grains, non-alcoholic beverages, and other foods) were derived by estimating the survey-weighted mean FAH and FAFH prices for each food group and dividing the FAHF price by the FAH price. These coefficients were multiplied by the price of each FAFH in PPPT to estimate their FAFH price. For example, if the price of a given dairy food was $1.35 (from PPPT), and if the mean price of FAFH dairy was 2.06 times greater than the mean price of FAH dairy (from FoodAPS), the adjusted price of that given dairy food would be estimated as $2.78 ($1.35 × 2.06).

Retail loss, consumer waste, and inedible portions

Data on GHGE, CED, and WSF from dataFIELD only represent the impacts associated with the consumed portion of food and do not include the impacts associated with food loss and waste that occur at the retail and consumer levels [35]. Similarly, data on food prices from PPPT only represent the price of the consumed portion of food and do not include the cost associated with the portions that are lost or wasted after purchase [47]. Given that approximately 30% of the US food supply is lost or wasted [48], not accounting for these food portions will severely underestimate the sustainability impacts of diet patterns.

To address these data gaps, the present study used established methods [49] to estimate the mass quantity of each NHANES food lost and wasted. These data were applied to data on GHGE, CED, and WSF from dataFIELD to estimate the impacts associated with Total Food Demand (TFD), which represents the sum of these impacts from retail loss, inedible portions, consumer waste, and consumed food. These data were also applied to data on food prices from PPPT to estimate the monetary cost of purchased food, which represents the sum of costs associated with consumer food waste, inedible portions, and consumed food. This method has been demonstrated and described in detail elsewhere [19, 43–45, 49]. Briefly, each food in NHANES was disaggregated into its constituent ingredients using FCID and matched to discrete food commodities in the USDA Loss-adjusted Food Availability data system (LAFA) , which provided data on the amount of food lost and wasted at the retail and consumer levels.

Statistical analyses

Mean environmental impacts, agricultural resource requirements, and diet cost were estimated for each quintile of the Mediterranean Diet Score using linear regression models adjusted for kcal (continuous) and survey cycle (continuous). These regression models were also used to evaluate the linear relationship between the Mediterranean Diet Score and each sustainability indicator measured continuously, at $p < 0.05$ using Wald tests. Sensitivity analyses were used to evaluate the effect of food loss and waste calculations on environmental impacts and diet cost, and additional sensitivity analyses evaluated the effect of FAFH prices on diet cost. All analyses accounted for the multistage probability sampling design of NHANES using standardized procedures and variables provided by the National Center for Health Statistics. Stata16.1 (StataCorp; College Station, TX) was used for data management and analysis.

Results

Participant characteristics

Dietary data were provided by 33,325 NHANES respondents from 2011–2018. Respondents were excluded if they were < 20 y ($n = 13{,}719$), pregnant or breastfeeding ($n = 359$), and had ≥ 1 sustainability impact (diet quality, GHGE, or diet cost) that was > 3SD from the mean ($n = 2{,}168$). The final analytic sample included 17,079 respondents (Table 1). Those with greater adherence to the Mediterranean diet pattern were more likely to be older and female, less likely to be non-Hispanic white, and have greater educational attainment and income-to-poverty ratio.

Food intake

Greater adherence to the Mediterranean diet pattern was associated with higher intake of protein foods ($p < 0.001$), yet the associations were heterogenous across food types: the intake of beef and pork decreased, the intake of poultry, seafood, and plant proteins increased ($p < 0.001$ for all outcomes), and there was no association with the intake of lamb, goat, and game ($p = 0.514$), organ meat ($p = 0.097$), and eggs ($p = 0.721$; Supplemental Table 2). The intake of grains increased as adherence to the Mediterranean diet pattern increased ($p = 0.011$),

Table 1 Characteristics of study participants, 2011–2018 ($n = 17,079$)

Characteristic	Mediterranean diet score[a]				
	Quintile 1 (n = 3,977)	Quintile 2 (n = 3,832)	Quintile 3 (n = 3,782)	Quintile 4 (n = 2,852)	Quintile 5 (n = 2,636)
	% (95% CI)[b]				
Mediterranean diet score, range[a]	0.00–2.00	2.01–3.00	3.01–4.00	4.01–5.00	5.01–8.00
Age, y					
20–30	25.5 (23.2, 27.9)	20.6 (18.1, 23.3)	18.5 (16.3, 21)	15.9 (13.5, 18.7)	14.1 (12.1, 16.4)
31–50	36.3 (34.2, 38.3)	33.6 (31.3, 35.9)	33.6 (31, 36.3)	34.1 (31, 37.3)	29.9 (27.2, 32.8)
51–70	28.6 (26.9, 30.4)	34.0 (31.3, 36.7)	35.1 (32.3, 38)	35.5 (32.1, 39)	40.9 (37.3, 44.6)
> 70	9.7 (8.4, 11.1)	11.9 (10.6, 13.3)	12.9 (11.4, 14.6)	14.5 (12.8, 16.4)	15.1 (13.2, 17.3)
Sex					
Male	48.1 (46.1, 50.1)	47.8 (45.6, 50)	45.7 (42.9, 48.6)	43.6 (40.9, 46.4)	43.1 (40.3, 45.9)
Female	51.9 (49.9, 53.9)	52.2 (50, 54.4)	54.3 (51.4, 57.1)	56.4 (53.6, 59.1)	56.9 (54.1, 59.7)
Education					
< High school	16.3 (14.6, 18.3)	14.2 (12.4, 16.2)	13.6 (12.1, 15.4)	12.6 (10.8, 14.7)	9.3 (7.7, 11.1)
High school or equivalent	28.7 (26.3, 31.3)	25.2 (23, 27.5)	21.8 (19.6, 24.2)	9.5 (17.1, 22.1)	15.5 (13.3, 17.9)
Some college	34.2 (32, 36.4)	35.1 (32.4, 37.8)	34.1 (31.5, 36.8)	29.1 (26.2, 32.1)	28.5 (25.7, 31.4)
College graduate	20.8 (18.1, 23.7)	25.5 (22.7, 28.4)	30.4 (27.2, 33.9)	38.8 (35.2, 42.6)	46.8 (43, 50.7)
Income-to-poverty ratio					
≤ 1.30	28.5 (25.8, 31.3)	25.3 (22.8, 27.9)	23.8 (21.6, 26.2)	18.3 (16.1, 20.8)	14.3 (12.4, 16.5)
1.31–1.99	14.3 (12.8, 16)	14.1 (12.6, 15.6)	14.0 (12.4, 15.8)	12.5 (10.8, 14.4)	11.0 (9.3, 13)
2.00–3.99	28.9 (26.5, 31.4)	28.3 (25.7, 31.1)	26.2 (23.8, 28.7)	27.6 (24.4, 31.1)	25.9 (22.4, 29.8)
≥ 4.00	28.3 (25.4, 31.4)	32.3 (29, 35.9)	36.0 (32.3, 39.8)	41.6 (37.7, 45.6)	48.8 (44.9, 52.6)
Race and Hispanic origin					
Non-Hispanic white	68.3 (64.3, 72)	65.5 (61.2, 69.5)	63.1 (58.9, 67.2)	66.2 (62.1, 70)	62.0 (58, 65.8)
Non-Hispanic black	12.5(10.3, 15.1)	12.3(10.1, 14.9)	12.0 (9.8, 14.5)	9.9 (8.1, 12.1)	9.2(7.6, 11)
Hispanic[c]	12.9 (10.9, 15.3)	15.5 (12.8, 18.6)	15.9 (13.6, 18.6)	13.6 (11.2, 16.4)	12.9 (10.5, 15.7)
Other[d]	6.3 (5.2, 7.6)	6.8 (5.6, 8.1)	9.0 (7.5, 10.7)	10.3 (8.7, 12.2)	15.9 (13.5, 18.8)

Sample sizes are unweighted

Within each quintile, differences between levels of each variable were evaluated using global Wald tests. All levels were significantly different from each other at $P < 0.001$ except for male vs. female in quintile 1 ($P = 0.394$) and quintile 2 ($P = 0.257$)

[a] Minimum possible score = 0, maximum possible score = 10. See O'Malley et al. (2023). Popular diets as selected by adults in the United States show wide variation in carbon footprints and diet quality. *American Journal of Clinical Nutrition*, 117:701–708

[b] Unless otherwise noted

[c] Includes Mexican American

[d] Includes multi racial

but this was driven by increased intake of whole grains, while the intake of refined grains decreased ($p < 0.001$ for both outcomes). No change in beverage intake was observed ($p = 0.626$), but the results were heterogenous across beverage types: lower intake of soft drinks, fruit flavored drinks, energy drinks, nutrition drinks ($p < 0.001$ for all outcomes), and alcohol ($p = 0.032$), higher intake of water ($p < 0.001$), and no change in coffee and tea intake ($p = 0.697$). Greater adherence to the Mediterranean diet was also associated with lower intake of dairy ($p < 0.014$), sandwiches, and desserts, and higher intake of soups, nuts and seeds, fruit, vegetables, and fats and oils ($p < 0.001$ for all outcomes except dairy).

Overall sustainability outcomes

Greater adherence to the Mediterranean diet pattern was associated with lower per capita GHGE (quintile 1 = 5.90 kg CO_2eq, 95% CI: 5.76–6.05 kg CO_2eq; quintile 5 = 4.40 kg CO_2eq, 4.20–4.61 CO_2eq), land use (quintile 1 = 22.28 m^2, 21.39–23.18 m^2; quintile 5 = 11.28 m^2, 10.28–12.27 m^2), fertilizer nutrient use (quintile 1 = 93.62 kg × 10^{-3}, 91.77–95.47 kg × 10^−3; quintile 5 = 72.59 kg × 10^{-3}, 70.72–74.47 kg × 10^{-3}), and pesticide use (quintile 1 = 2.49 kg × 10^{-3}, 2.42–2.56 kg × 10^{-3}; quintile 5 = 2.18 kg × 10^{-3}, 2.10–2.27 kg × 10^{-3}; $p < 0.001$ for all outcomes; Table 2). Greater adherence to the Mediterranean diet pattern was also associated with higher WSF (quintile

Table 2 Environmental impacts and cost of the Mediterranean diet pattern (*n*=17,079)

Impact	Mediterranean Diet Score[a]					
	Quintile 1 (*n*=3,977)	Quintile 2 (*n*=3,832)	Quintile 3 (*n*=3,782)	Quintile 4 (*n*=2,852)	Quintile 5 (*n*=2,636)	P-trend[b]
	Mean (95% CI) per capita per day					
Greenhouse gas emissions (kg CO_2eq)	5.90 (5.76-6.05)	5.40 (52-5.5.28)	5.09 (4.9-5.27)	4.68 (4.55-4.81)	4.40 (4.2-4.61)	<0.001
Cumulative energy demand (MJ)	28.42 (27.75-29.09)	26.89 (26.24-27.54)	27.28 (26.59-27.98)	27.00 (26.2-27.8)	29.50 (28.16-30.83)	0.336
Water scarcity footprint (L eq × 10^2)	32.77 (31.58-33.95)	34.74 (33.5-35.98)	36.63 (35.29-37.96)	39.81(38.26-41.37)	44.42 (42.6-46.23)	<0.001
Land use (m^2)	22.28 (21.39-23.18)	19.49 (18.34-20.63)	17.50 (16.42-18.59)	14.96 (14.01-15.91)	11.28 (10.28-12.27)	<0.001
Fertilizer nutrient use (kg × 10^{-3})	93.62 (91.77-95.47)	87.42 (85.28-89.56)	84.47 (82.32-86.61)	79.57 (77.55-81.6)	72.59 (70.72-74.47)	<0.001
Pesticide use (kg × 10^{-3})	2.49 (2.42-2.56)	2.42 (2.33-2.51)	2.38 (2.3-2.46)	2.31 (2.24-2.39)	2.18 (2.1-2.27)	<0.001
Diet cost (US $)	15.34 (14.8-15.89)	16.28 (15.68-16.89)	16.25 (15.72-16.78)	17.66 (17.11-18.22)	18.64 (17.96-19.32)	<0.001

All results were adjusted for kcal, and survey cycle using linear regression models

CO_2eq Carbon dioxide equivalent, *L eq* Liter equivalent

[a] Minimum possible score=0, maximum possible score=10

[b] Wald test for linear trend using regression analysis adjusted for kcal and survey cycle

1 = 32.77 L eq × 10^2, 31.58–33.95 m^3; quintile 5 = 44.42 L eq × 10^2, 42.60–46.23 L eq × 10^2) and diet cost (quintile 1 = \$15.34, \$14.80-\$15.89; quintile 5 = \$18.64, \$17.96-\$19.32; $p < 0.001$ for both outcomes), and not associated with cumulative energy demand (quintile 1 = 28.42 MJ, 27.75–29.09 MJ; quintile 5 = 29.50 MJ, 28.16–30.83 MJ; $p = 0.336$).

Environmental impacts by food category

Figure 1 displays the share of GHGE from each food category within each quintile of the Mediterranean diet score. As adherence to the Mediterranean diet pattern increased, the greatest decrease in GHGE was observed for meat sandwiches (decreased from 19% in quintile 1 to 9% in quintile 5), followed by beef (19% to 11%), and refined grains (14% to 11%). The share of GHGE from seafood increased from < 1% in quintile 1 to 9% in quintile 5. The contribution of other food categories to GHGE did not exceed 10% in any quintile. The greatest decrease in the share of CED (Supplemental Fig. 1) was observed for soft drinks (decreased from 18% in quintile 1 to 5% in quintile 5), followed by meat sandwiches (12% to 4%),

	Mediterranean Diet Score				
Food category[1]	Quintile 1 (n=3,977)	Quintile 2 (n=3,832)	Quintile 3 (n=3,782)	Quintile 4 (n=2,852)	Quintile 5 (n=2,636)
Milk and cream	5%	4%	5%	4%	4%
Cheese	4%	3%	3%	2%	2%
Yogurt	1%	1%	1%	1%	1%
Dairy alternatives	0%	0%	0%	0%	0%
Beef	19%	18%	19%	14%	11%
Pork	3%	3%	2%	2%	2%
Lamb, goat, and game	1%	1%	1%	1%	1%
Organ meat	0%	0%	0%	0%	0%
Poultry	3%	4%	6%	6%	6%
Seafood	0%	1%	3%	4%	9%
Eggs	2%	2%	3%	3%	3%
Meat and egg alternatives	0%	0%	0%	0%	0%
Legumes	0%	0%	0%	0%	1%
Meat sandwiches	19%	16%	12%	13%	9%
Seafood sandwiches	0%	0%	0%	0%	0%
Egg sandwiches	0%	0%	0%	0%	0%
Nut butter sandwiches	0%	0%	0%	0%	0%
Soup	1%	2%	2%	3%	4%
Nuts and seeds	0%	0%	0%	1%	1%
Refined grains	14%	14%	13%	13%	11%
Whole grains	1%	1%	2%	2%	2%
Whole fruit	1%	2%	2%	4%	5%
Dried fruit	0%	0%	0%	0%	0%
Fruit juice	1%	1%	1%	2%	2%
Dark green vegtables	0%	0%	0%	0%	1%
Red and orange vegetables	0%	0%	0%	0%	1%
Potatoes	1%	1%	1%	1%	1%
Other vegetables	2%	2%	3%	4%	5%
Table fat	0%	1%	1%	1%	1%
Vegtable oil	0%	0%	0%	0%	0%
Salad dressing	0%	0%	0%	0%	0%
Desserts	4%	4%	4%	4%	4%
Coffee and tea	2%	1%	2%	2%	2%
Soft drinks	8%	6%	6%	5%	3%
Nutrition drinks	1%	1%	2%	1%	1%
Water	0%	0%	0%	0%	0%
Alcohol	4%	4%	3%	4%	4%
Other foods	2%	2%	2%	2%	2%

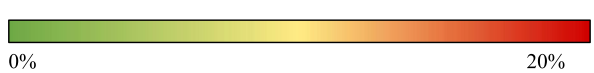

Fig. 1 Contribution of food categories to mean daily per capita greenhouse gas emissions, 2011–2018 ($n = 17{,}079$). [1]Represents predominant ingredient in mixed dish. All results were adjusted for kcal, and survey cycle using linear regression models. CO_2eq, carbon dioxide equivalent

and refined grains (12% to 8%). The share of CED from seafood increased from 1% in quintile 1 to 23% in quintile 5 as adherence to the Mediterranean diet pattern increased. The contribution of other food categories to CED did not exceed 10% in any quintile. The greatest decrease in the share of WSF (Supplemental Fig. 2) was observed for meat sandwiches (decreased from 11% in quintile 1 to 3% in quintile 5), followed by refined grains (12% to 6%), beef (10% to 4%), and alcohol (16% to 12%). The share of WSF from whole fruit increased from 3% in quintile 1 to 16% in quintile 5, followed by nuts and seeds (1% to 14%). The contribution of other food categories to WSF did not exceed 10% in any quintile.

Agricultural resource requirements by food category

As adherence to the Mediterranean diet pattern increased, the share of land attributable to beef production decreased from 79% in quintile 1 to 64% in quintile 5 (Supplemental Fig. 3). All other changes in land use for individual food categories were modest and their share did not exceed 10% in any quintile. The share of fertilizer nutrients (Supplemental Fig. 4) attributable to dairy decreased from 31% in quintile 1 to 20% in quintile 5 as adherence to the Mediterranean diet pattern increased, followed by beef (27% to 14%). The share of grains to WSF increased from 12 to 14%, and the contribution of other food categories did not exceed 10% in any quintile. Greater adherence to the Mediterranean diet pattern was associated with a decrease in the share of pesticides (Supplemental Fig. 5) used for beef production (44% in quintile 1 to 20% in quintile 5) and dairy (22% to 11%). The share of pesticides used for whole and frozen fruit increased from 2% in quintile 1 to 10% in quintile 5, and the contribution of other food categories did not exceed 10% in any quintile.

Contribution of food categories to diet cost

As adherence to the Mediterranean diet increased, the share of food spending on meat sandwiches decreased from 20% in quintile 1 to 8% in quintile 5, and the share of food spending on refined grains decreased from 15% in quintile 1 to 10% in quintile 5 (Fig. 2). An increase in the share of food spending was observed for seafood (1% in quintile 1 to 10% in quintile 5) and the contribution of other food categories did not exceed 10% in any quintile.

Sensitivity analyses

Removing the adjustment for losses and waste lowered GHGE, CED, WSF (Supplemental Table 3), and diet cost (Supplemental Table 4) by 29–41% for all quintiles but the trend across quintiles remained unchanged ($p < 0.001$ for GHGE and WSF, and $p > 0.05$ for CED). Removing the adjustment for FAFH prices further lowered diet cost by 31–36% for all quintiles but the trend across quintiles remained unchanged ($p < 0.001$).

Discussion

In this nationally representative study of over 17,000 US adults, greater adherence to the Mediterranean diet pattern was associated with sustainability trade-offs: lower GHGE, land use, fertilizer nutrient use, and pesticide use, higher WSF and diet cost, and no change in CED. These findings have implications for the development of sustainable dietary guidelines and clinical practice guidelines that can be used to inform consumer food choices.

This study is consistent with prior research using nationally representative individual-level dietary data in the US, which demonstrated that greater adherence to the Mediterranean diet pattern was associated with lower GHGE [27]. These findings are also consistent with prior international studies that showed greater adherence to the Mediterranean diet pattern was associated with lower GHGE [21, 23, 24, 50, 51] and land use [21, 51], and higher diet costs [51–53]; but some studies showed no association with land, water, and energy [24], and an inverse association with diet cost [50]. These differences may be due to differences in source populations and environmental data sources. In the present study, the share of sustainability impacts from animal-sourced foods (beef, meat sandwiches, and dairy), soft drinks, and refined grains decreased as adherence to the Mediterranean diet increased, although the share remained higher than most other food categories even in quintile 5 (greatest adherence group). The exception was seafood, which was associated with an increased share of sustainability impacts, particularly GHGE, as adherence to the Mediterranean diet pattern increased. These findings are generally consistent with prior research in the US [25, 26] and Europe [20, 54–57] that showed that animal-sourced foods and grains contributed the greatest share of environmental impacts in the Mediterranean diet pattern.

To our knowledge, this is the first study to use individual-level dietary data in the US to evaluate the association between adherence to the Mediterranean diet and CED, pesticide use, WSF, and diet cost in a nationally representative sample. These findings support a growing body of research that demonstrates that adherence to healthy diet patterns is often associated with sustainability trade-offs [58, 59]. For example, higher scores on the HEI-2015 have been associated with higher use of pesticides and irrigation water [19]. Others have shown that higher scores on the HEI-2015 were not associated with lower GHGE for some popular diet patterns (plant-based and time restricted diet patterns), and were associated with higher cost for others (plant-based, low grain, restricted carbohydrate, and low fat diet patterns)

Food category[1]	Mediterranean Diet Score Quintile 1 (n=3,977)	Quintile 2 (n=3,832)	Quintile 3 (n=3,782)	Quintile 4 (n=2,852)	Quintile 5 (n=2,636)
Milk and cream	3%	2%	2%	1%	1%
Cheese	3%	2%	2%	2%	1%
Yogurt	1%	1%	1%	1%	1%
Dairy alternatives	0%	0%	0%	0%	0%
Beef	8%	6%	5%	4%	3%
Pork	5%	4%	4%	3%	2%
Lamb, goat, and game	0%	0%	0%	0%	0%
Organ meat	0%	0%	0%	0%	0%
Poultry	6%	8%	9%	9%	8%
Seafood	1%	2%	4%	5%	10%
Eggs	3%	3%	3%	2%	2%
Meat and egg alternatives	0%	0%	0%	0%	0%
Legumes	0%	0%	0%	1%	1%
Meat sandwiches	20%	17%	12%	11%	8%
Seafood sandwiches	0%	0%	0%	1%	1%
Egg sandwiches	1%	1%	1%	1%	0%
Nut butter sandwiches	0%	0%	0%	0%	0%
Soup	1%	2%	2%	2%	4%
Nuts and seeds	0%	0%	1%	2%	3%
Refined grains	15%	15%	14%	12%	10%
Whole grains	2%	4%	4%	5%	5%
Whole fruit	2%	5%	6%	8%	9%
Dried fruit	0%	0%	0%	0%	0%
Fruit juice	1%	1%	1%	1%	1%
Dark green vegtables	1%	1%	1%	1%	2%
Red and orange vegetables	1%	1%	1%	1%	2%
Potatoes	2%	2%	2%	2%	1%
Other vegetables	5%	5%	6%	8%	9%
Table fat	0%	0%	0%	0%	0%
Vegtable oil	0%	0%	0%	0%	0%
Salad dressing	0%	0%	0%	0%	0%
Desserts	5%	5%	5%	5%	4%
Coffee and tea	2%	3%	3%	2%	2%
Soft drinks	3%	2%	2%	1%	1%
Nutrition drinks	1%	0%	1%	0%	0%
Water	1%	1%	1%	1%	1%
Alcohol	6%	5%	4%	5%	4%
Other foods	2%	1%	2%	2%	2%

Fig. 2 Contribution of food categories to mean daily diet cost (US $), 2011–2018 ($n$ = 17,079). [1]Represents predominant ingredient in mixed dish. All results were adjusted for kcal, and survey cycle using linear regression models

. Healthy plant-based diet patterns have been associated with lower GHGE and irrigation water use, but unhealthy plant-based diet patterns were not [60]. Furthermore, recent studies have shown that popular diet patterns with the highest HEI-2015 scores are not associated with the lowest GHGE and cost . Nutrition-environment tradeoffs have recently been documented in international settings [61].

Over one-half of US adults reported following a specific diet pattern in 2023, and 12% reported that environmental sustainability was one of their motivations for adopting a new diet pattern [13]. Over one-third of adults also reported that concern about environmental sustainability was a primary motivator for their food purchasing decisions [13]. Others have shown that targeted dietary shifts among people motivated to change their diet (16% of the population) can reduce GHGE by nearly 7% [62], which suggests that there is an opportunity for a larger reduction in environmental impacts if public messaging can motivate more people to change their diet. Given that recent research has demonstrated the sustainability trade-offs of popular diet patterns [45], and given the need for urgent action to meet global sustainability targets related to food systems [63], nuanced discussions about how to disseminate this information to the public is needed.

The primary vehicle for disseminating nutrition information to the US public is the Dietary Guidelines for Americans (DGA), and some have called for broadening its scope to include information about sustainable food choices [64–66]. The DGA already includes the Mediterranean diet pattern as one of its Healthy Eating Patterns, but only 5% of US adults report following it [67], so there is clearly a need and an opportunity to further emphasize its nutritional benefits. However, initiatives to include information about the sustainability impacts of the Mediterranean diet pattern in the DGA should be carefully considered. The present study shows that greater adherence to the Mediterranean diet is associated with mixed sustainability impacts: some impacts decrease (GHGE and use of land, fertilizer nutrients, and pesticide), some increase (WSF and diet cost), and some do not change (CED). As noted above, these trade-offs are consistent with prior research which demonstrates that healthier diets, including DGA-recommended diets, are often associated with mixed sustainability impacts, including higher diet cost [19, 44]. These trade-offs are particularly important to consider given that over 75% of US consumers reported that price was a primary driver of their food purchasing decisions (behind only taste), and only 16% of US consumers reported they would pay more for the most environmentally friendly food option [67]. Similar findings have been reported in other high income countries, mostly in Europe [68, 69].

These trade-offs raise important questions about how to communicate this nuanced information to the public without undermining the central message of the DGA to make healthy dietary choices. Over 50% of adults report knowing very little about the DGA or have never heard of it [67], and only 20% report having heard of MyPlate (the icon used to convey the primary recommendations in the DGA) [70]. Less than 5% of adults meet dietary recommendations [71] and suboptimal diet is the leading modifiable risk factor for mortality [72], which underscores the need for the DGA to retain its original intent to communicate nutrition information to the public. It is worthwhile to consider whether more consumers will adopt the Mediterranean diet pattern if they are told that it is healthy but costs more, and that it will reduce some environmental outcomes but not others. Consumers are already unsure about how diets are linked to environmental impacts and how to define sustainability [59, 68, 69]. Given that readership is already lower than optimal, it is unclear whether the DGA is the appropriate venue to communicate these nuanced messages. It is prudent for the professional nutrition community to thoughtfully address these gaps before broadening the scope of the DGA to include sustainability [69]. It is also important to consider that consumers face numerous barriers to adopting sustainable diets that cannot be fully addressed through public messaging, and may require more systemic interventions [73].

Clinicians also play a crucial role in disseminating nutrition information to the public because many of their patients turn to them as a source of information on sustainable food choices [64–66, 74–76]. In a 2023 survey of US Registered Dietitians (RDs), the majority (64%) reported that their patients were moderately to very interested in sustainability and nearly all (95%) believed they should help advocate for sustainable food systems [77], which is similar to other findings [75]. The majority (62%) also believed that sustainability should be incorporated into the DGAs. Although 70% of RDs reported they were moderately to very confident in their ability to provide guidance on sustainable food choices, only 13% received formal training in sustainability, either through internships or formal coursework [77]. A similar disconnect was observed among a sample of European dietitians: nearly two-thirds reported being aware of sources of information on sustainability, yet only 25% ever received formal training [76]. Many RDs have reported they lack the skills, knowledge, and evidence-based information needed to integrate sustainable nutrition training into their practice [75]. These findings suggest that clinicians can play an important role in disseminating information about sustainable food choices, but they lack the requisite training. This training should include instruction on how to interpret scientific literature, especially when it demonstrates sustainability trade-offs, such as demonstrated by the present study.

Others have called for inclusion of sustainability in clinical practice guidelines in order to address current environmental trends caused by diet patterns and agricultural practices [64, 74, 75]. In the US, RDs have the opportunity to enhance their training in sustainable food systems by engaging with the Standards of Professional Practice (SOPP) in Sustainable, Resilient, and Healthy Food and Water Systems through the Academy of Nutrition and Dietetics [74]. This SOPP provides training to allow practitioners to progress from competent (e.g., may be able to contribute to sustainable meal plans, advocate for institutional policies), to proficient (can tailor interventions to meet sustainability objectives, collaborate with experts from outside of the profession), to expert (can collaborate with experts from a broad range of sustainability fields such as agriculture, environmental science, public health, public policy, and economics, can guide interprofessional teams, and develop new policies and programs) [74]. RDs who have achieved expert status in this SOPP will be able to understand the nuances of sustainability research and are well poised to disseminate this information to their clients and colleagues.

The strengths of this study include the nationally representative sampling design of NHANES, which makes these findings generalizable to the US adult population. To our knowledge, this is the first nationally representative study using individual-level dietary data in the US to evaluate the association between adherence to the Mediterranean diet and multiple sustainability domains (health/nutrition, environment, economic) and indicators (Mediterranean Diet Score, GHGE, CED, WSF, land, fertilizer nutrients, pesticides, and diet cost). To comprehensively account for these sustainability impacts, this study incorporated data on inedible portions, consumer waste, and FAFH prices, and conducted sensitivity analyses which demonstrated the robustness of these methods. This study also has several limitations. Data on social sustainability are emerging [78] but have not been linked to NHANES foods, which prevented their inclusion in this study. Data on food prices only represent the price of food, and do not include other food-related costs such as kitchen appliances and household utilities (electricity, natural gas, water, etc.). All dietary recalls are subject to recall bias, which can occur when respondents forget foods they consumed, misunderstand recall instructions, or intentionally modify their reported food intake to avoid perceived negative judgement by the interviewer.

Conclusions

This nationally representative study of US adults shows that greater adherence to the Mediterranean diet pattern is associated with sustainability trade-offs. Given the demonstrated health benefits of the Mediterranean diet pattern, these trade-offs raise questions about how to communicate this nuanced information to the public without undermining standard clinical and public health messages to improve diet quality for health promotion. Despite enthusiasm from some in the professional community to include sustainability into the DGA, greater care is needed to ensure that it retains its central purpose of providing clear and evidence-based nutrition information to the public. The role of clinicians in communicating nuanced information about diet sustainability to their patients cannot be overstated, but will require that more clinicians receive formal training in clinical practice guidelines for sustainable food choices.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-024-01050-z.

Supplemental Table 1. Food and beverage categorization.

Supplemental Table 2. Contribution of food categories to mean daily per capita food intake, 2011-2018 (n=17,079).

Supplemental Table 3. Sensitivity analysis of mean daily per capita environmental impacts without adjustment for losses and waste, 2011-2018 (n=17,079).

Supplemental Table 4. Sensitivity analysis of mean daily diet costs with and without food away from home prices, 2011-2018 (n=17,079).

Supplemental Figure 1. Contribution of food categories to mean daily per capita cumulative energy demand, 2011-2018 (n=17,079).

Supplemental Figure 2. Contribution of food categories to mean daily per capita water scarcity footprint, 2011-2018 (n=17,079).

Supplemental Figure 3. Contribution of food categories to mean daily per capita land use, 2011-2018 (n=17,079).

Supplemental Figure 4. Contribution of food categories to mean daily per capita fertilizer nutrient use, 2011-2018 (n=17,079).

Supplemental Figure 5. Contribution of food categories to mean daily per capita pesticide use, 2011-2018 (n=17,079).

Authors' contributions

Conception: ZC; Design: ZC; Acquisition: ZC, MK, CD, and SW; Interpretation: ZC, MK, CD; drafted the work: ZC and MK; Revised the work: ZC, MK, CD, and SW. All authors approve of the submitted study and any substantially modified version that invites the authors' contribution; and agree to be personally accountable for their own contributions.

Funding

Margaret S. Glauber Faculty-Student Fellowship at William & Mary and the Office of the Vice Provost at William & Mary.

Data availability

The datasets used in this study are publicly available: https://www.cdc.gov/nchs/nhanes/index.htm; http://fcid.foodrisk.org/#; https://css.umich.edu/page/datafield; https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/; https://www.ers.usda.gov/data-products/foodaps-national-household-food-acquisition-and-purchase-survey/; https://www.ers.usda.gov/data-products/purchase-to-plate/.

Declarations

Ethics approval and consent to participate

This is a secondary analysis of publicly available data and was deemed exempt from human ethics review by the Institutional Review Board at William & Mary.

Consent for publication

Not applicable.

Competing interests

ZC is an Associate Editor of this journal and has research awards from the US Department of Agriculture, the Jeffress Trust for Research Advancing Health Equity, and the National Pork Board. All other authors declare no competing interests.

Received: 5 April 2024 Accepted: 13 November 2024
Published online: 20 December 2024

References

1. Bach-Faig A, Berry EM, Lairon D, Reguant J, Trichopoulou A, Dernini S, Medina FX, Battino M, Belahsen R, Miranda G, et al. Mediterranean diet pyramid today. Science and cultural updates. Public Health Nutr. 2011;14:2274–84.
2. Guasch-Ferre M, Willett WC. The Mediterranean diet and health: a comprehensive overview. J Intern Med. 2021;290:549–66.
3. Muscogiuri G, Verde L, Sulu C, Katsiki N, Hassapidou M, Frias-Toral E, Cucalon G, Pazderska A, Yumuk VD, Colao A, Barrea L. Mediterranean Diet and Obesity-related Disorders: What is the Evidence? Curr Obes Rep. 2022;11:287–304.
4. Neuenschwander M, Hoffmann G, Schwingshackl L, Schlesinger S. Impact of different dietary approaches on blood lipid control in patients with type 2 diabetes mellitus: a systematic review and network meta-analysis. Eur J Epidemiol. 2019;34:837–52.
5. Martinez-Gonzalez MA, Gea A, Ruiz-Canela M. The Mediterranean Diet and Cardiovascular Health. Circ Res. 2019;124:779–98.
6. Rosato V, Temple NJ, La Vecchia C, Castellan G, Tavani A, Guercio V. Mediterranean diet and cardiovascular disease: a systematic review and meta-analysis of observational studies. Eur J Nutr. 2019;58:173–91.
7. Rees K, Takeda A, Martin N, Ellis L, Wijesekara D, Vepa A, Das A, Hartley L, Stranges S. Mediterranean-style diet for the primary and secondary prevention of cardiovascular disease. Cochrane Database Syst Rev. 2019;3:CD009825.
8. Gardner CD, Vadiveloo MK, Petersen KS, Anderson CAM, Springfield S, Van Horn L, Khera A, Lamendola C, Mayo SM, Joseph JJ, et al. Popular Dietary Patterns: Alignment With American Heart Association 2021 Dietary Guidance: A Scientific Statement From the American Heart Association. Circulation. 2023;147:1715–30.
9. Lichtenstein AH, Appel LJ, Vadiveloo M, Hu FB, Kris-Etherton PM, Rebholz CM, Sacks FM, Thorndike AN, Van Horn L, Wylie-Rosett J. 2021 Dietary Guidance to Improve Cardiovascular Health: A Scientific Statement From the American Heart Association. Circulation. 2021;144:e472–87.
10. U.S. Department of Agriculture and U.S. Department of Health and Human Services: Dietary Guidelines for Americans 2020–2025. vol. 9th Edition2020.
11. United Nations Department of Global Communications: Sustainable Development Goals. 2023.
12. The White House: Biden-Harris Administration National Strategy on Hunger, Nutrition, and Health. 2022.
13. International Food Information Council: 2023 Food and Health Survey. 2023.
14. Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planet Health. 2018;2:e451–61.
15. Ambikapathi R, Schneider KR, Davis B, Herrero M, Winters P, Fanzo JC. Global food systems transitions have enabled affordable diets but had less favourable outcomes for nutrition, environmental health, inclusion and equity. Nat Food. 2022;3:764–79.
16. Conrad Z, Drewnowski A, Love DC: Greater adherence to the Dietary Guidelines for Americans is associated with lower diet-related greenhouse gas emissions but higher costs. Frontiers in Nutrition. 2023;10.
17. He P, Feng K, Baiocchi G, Sun L, Hubacek K. Shifts towards healthy diets in the US can reduce environmental impacts but would be unaffordable for poorer minorities. Nat Food. 2021;2:664–72.
18. Carrillo-Álvarez E, Muñoz-Martínez J, Salinas-Roca B, Cussó-Parcerisas I. Estimating the Cost of the Spanish Sustainable Food Basket through the Reference Budgets Approach. Sustainability. 2021;13:9401.
19. Conrad Z, Blackstone NT, Roy ED. Healthy diets can create environmental trade-offs, depending on how diet quality is measured. Nutr J. 2020;19:117.
20. Castaldi S, Dembska K, Antonelli M, Petersson T, Piccolo MG, Valentini R. The positive climate impact of the Mediterranean diet and current divergence of Mediterranean countries towards less climate sustainable food consumption patterns. Sci Rep. 2022;12:8847.
21. Fresan U, Martinez-Gonzalez MA, Sabate J, Bes-Rastrollo M. The Mediterranean diet, an environmentally friendly option: evidence from the Seguimiento Universidad de Navarra (SUN) cohort. Public Health Nutr. 2018;21:1573–82.
22. Fresan U, Martinez-Gonzalez MA, Sabate J, Bes-Rastrollo M. Global sustainability (health, environment and monetary costs) of three dietary patterns: results from a Spanish cohort (the SUN project). BMJ Open. 2019;9: e021541.
23. Garcia S, Bouzas C, Mateos D, Pastor R, Alvarez L, Rubin M, Martinez-Gonzalez MA, Salas-Salvado J, Corella D, Goday A, et al. Carbon dioxide (CO(2)) emissions and adherence to Mediterranean diet in an adult population: the Mediterranean diet index as a pollution level index. Environ Health. 2023;22:1.
24. Grosso G, Fresan U, Bes-Rastrollo M, Marventano S, Galvano F: Environmental Impact of Dietary Choices: Role of the Mediterranean and Other Dietary Patterns in an Italian Cohort. Int J Environ Res Public Health. 2020;17.
25. Blackstone NT, El-Abbadi NH, McCabe MS, Griffin TS, Nelson ME. Linking sustainability to the healthy eating patterns of the Dietary Guidelines for Americans: a modelling study. Lancet Planet Health. 2018;2:e344–52.
26. Jennings R, Henderson AD, Phelps A, Janda KM, van den Berg AE: Five U.S. Dietary Patterns and Their Relationship to Land Use, Water Use, and Greenhouse Gas Emissions: Implications for Future Food Security. Nutrients. 2023;15.
27. O'Malley K, Willits-Smith A, Rose D. Popular diets as selected by adults in the United States show wide variation in carbon footprints and diet quality. Am J Clin Nutr. 2023;117:701–8.
28. US Department of Health and Human Services, Centers for Disease Control and Prevention (CDC): About the National Health and Nutrition Examination Survey. 2023.
29. National Cancer Institute, National Institutes of Health: Recommendations on Potential Approaches to Dietary Assessent for Different Research Objectives Requiring Group-level Estimates. 2024.
30. US Department of Agriculture, Agricultural Research Service: Food and Nutrient Database for Dietary Studies. 2023.
31. US Department of Agriculture, Agricultural Research Service: Food Patterns Equivalents Database (FPED). 2023.
32. Trichopoulou A, Costacou T, Bamia C, Trichopoulos D. Adherence to a Mediterranean diet and survival in a Greek population. N Engl J Med. 2003;348:2599–608.
33. Center for Sustainable Systems, University of Michigan: Database of Food Impacts on the Environment for Linking to Diets. 2023.
34. Heller MC, Willits-Smith A, Mahon T, Keoleian GA, Rose D. Individual US diets show wide variation in water scarcity footprints. Nature Food. 2021;2:255–63.
35. Heller MC, Willits-Smith A, Meyer R, Keoleian GA, Rose D. Greenhouse gas emissions and energy use associated with production of individual self-selected US diets. Environ Res Lett. 2018;13: 044004.
36. US Environmental Protection Agency: Food Commodity Intake Database (FCID). 2001–2010.
37. Conrad Z, Cyril A, Kowalski C, Jackson E, Hendrickx B, Lan JJ, McDowell A, Salesses M, Love DC, Wiipongwii T, et al: Diet sustainability analyses can be improved with updates to the Food Commodity Intake Database. Frontiers in Nutrition. 2022;9.
38. Conrad Z, Wu S, Johnson LK, Kun JF, Roy ED, Gephart JA, Bezares N, Wiipongwii T, Blackstone NT, Love DC: Foodprint 2.0: A computational simulation model that estimates the agricultural resource requirements of diet patterns. PLOS One (in press) 2024.
39. US Department of Agriculture, Economic Research Service: Purchase to Plate Suite. 2024.
40. Levin D, Noriega D, Dicken C, Okrent AM, Harding M, Lovenheim M: Examining food store scanner data: a comparison of the IRI InfoScan data with other data sets, 2008–2012. US Department of Agriculture, Economic Research Service; 2018.
41. Carlson A, Kuczynski K, Pannucci T, Koegel K, Page ET, Tornow CE, Zimmerman TP. Estimating prices for foods in the National Health and Nutrition Examination Survey: the Purchase to Plate Price Tool. Washington, DC: US Department of Agriculture, Economic Research Service; 2020.
42. Okrent A, Elitzak H, Park T, Rehkamp S: Measuring the value of the U.S. food system: Revisions to the Food Expenditure Series. Washington, DC: US Department of Agriculture, Economic Research Service; 2018.
43. Conrad Z. Daily cost of consumer food wasted, inedible, and consumed in the United States, 2001–2016. Nutr J. 2020;19:35.

44. Conrad Z, Reinhardt S, Boehm R, McDowell A: Higher diet quality is associated with higher diet costs when eating at home and away from home: National Health and Nutrition Examination Survey, 2005–2016. Public Health Nutr 2021:1–29.
45. Conrad Z, Drewnowski A, Belury MA, Love DC. Greenhouse gas emissions, cost, and diet quality of specific diet patterns in the United States. Am J Clin Nutr. 2023;117:1186–94.
46. US Department of Agriculture, Economic Research Service: National Household Food Acquisition and Purchase Survey. 2012–2013. Available at: https://www.ers.usda.gov/data-products/foodaps-national-household-food-acquisition-and-purchase-survey/. (verified 19 September 2024).
47. Carlson AC, Tornow CE, Page ET, Brown McFadden A, Palmer Zimmerman T. Development of the Purchase to Plate Crosswalk and Price Tool: Estimating prices for the National Health And Nutrition Examination Survey (NHANES) foods and measuring the healthfulness of retail food purchases. J Food Compos Anal. 2022;106: 104344.
48. US Department of Agriculture, Economic Research Service: Food loss: estimates of food loss at the retail and consumer levels. 2020. Available at: https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/food-loss/#howmuch. (verified 31 August 2023).
49. Conrad Z, Niles MT, Neher DA, Roy ED, Tichenor NE, Jahns L. Relationship between food waste, diet quality, and environmental sustainability. PLoS ONE. 2018;13: e0195405.
50. Gualtieri P, Marchetti M, Frank G, Cianci R, Bigioni G, Colica C, Soldati L, Moia A, De Lorenzo A, Di Renzo L: Exploring the Sustainable Benefits of Adherence to the Mediterranean Diet during the COVID-19 Pandemic in Italy. Nutrients. 2022;15.
51. Baudry J, Neves F, Lairon D, Alles B, Langevin B, Brunin J, Berthy F, Danquah I, Touvier M, Hercberg S, et al. Sustainability analysis of the Mediterranean diet: results from the French NutriNet-Sante study. Br J Nutr. 2023;130:2182–97.
52. Schroder H, Gomez SF, Ribas-Barba L, Perez-Rodrigo C, Bawaked RA, Fito M, Serra-Majem L. Monetary Diet Cost, Diet Quality, and Parental Socioeconomic Status in Spanish Youth. PLoS ONE. 2016;11: e0161422.
53. Rubini A, Vilaplana-Prieto C, Flor-Alemany M, Yeguas-Rosa L, Hernandez-Gonzalez M, Felix-Garcia FJ, Felix-Redondo FJ, Fernandez-Berges D. Assessment of the Cost of the Mediterranean Diet in a Low-Income Region: Adherence and Relationship with Available Incomes. BMC Public Health. 2022;22:58.
54. Sáez-Almendros S, Obrador B, Bach-Faig A, Serra-Majem L. Environmental footprints of Mediterranean versus Western dietary patterns: beyond the health benefits of the Mediterranean diet. Environ Health. 2013;12:118.
55. Pairotti MB, Cerutti AK, Martini F, Vesce E, Padovan D, Beltramo R. Energy consumption and GHG emission of the Mediterranean diet: a systemic assessment using a hybrid LCA-IO method. J Clean Prod. 2015;103:507–16.
56. Ulaszewska MM, Luzzani G, Pignatelli S, Capri E. Assessment of diet-related GHG emissions using the environmental hourglass approach for the Mediterranean and new Nordic diets. Sci Total Environ. 2017;574:829–36.
57. van Dooren C, Marinussen M, Blonk H, Aiking H, Vellinga P. Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. Food Policy. 2014;44:36–46.
58. Reinhardt SL, Boehm R, Blackstone NT, El-Abbadi NH, McNally Brandow JS, Taylor SF, DeLonge MS. Systematic Review of Dietary Patterns and Sustainability in the United States. Adv Nutr. 2020;11:1016–31.
59. Sproesser G, Arens-Azevedo U, Renner B. The "healthy = sustainable" heuristic: Do meal or individual characteristics affect the association between perceived sustainability and healthiness of meals? PLOS Sustainability and Transformation. 2023;2: e0000086.
60. Musicus AA, Wang DD, Janiszewski M, Eshel G, Blondin SA, Willett W, Stampfer MJ. Health and environmental impacts of plant-rich dietary patterns: a US prospective cohort study. The Lancet Planetary Health. 2022;6:e892–900.
61. Leonard UM, Leydon CL, Arranz E, Kiely ME: Impact of consuming an environmentally protective diet on micronutrients: a systematic literature review. The American Journal of Clinical Nutrition. 2024.
62. Willits-Smith A, Aranda R, Heller MC, Rose D. Addressing the carbon footprint, healthfulness, and costs of self-selected diets in the USA: a population-based cross-sectional study. The Lancet Planetary Health. 2020;4:e98–106.
63. United Nations: Sustainable Development Goals. 2023. Available at: https://sustainabledevelopment.un.org/?menu=1300. (verified 13 July 2023).
64. Rose D, Heller MC, Roberto CA. Position of the Society for Nutrition Education and Behavior: the importance of including environmental sustainability in dietary guidance. J Nutr Educ Behav. 2019;51:3-15.e11.
65. Ritchie H, Reay DS, Higgins P. The impact of global dietary guidelines on climate change. Glob Environ Chang. 2018;49:46–55.
66. Ahmed S, Downs S, Fanzo J: Advancing an Integrative Framework to Evaluate Sustainability in National Dietary Guidelines. Frontiers in Sustainable Food Systems. 2019;3.
67. International Food Information Council: Food and Health Survey. 2023.
68. van Bussel LM, Kuijsten A, Mars M, van 't Veer P: Consumers' perceptions on food-related sustainability: A systematic review. J Cleaner Prod. 2022;341.
69. Kenny TA, Woodside JV, Perry IJ, Harrington JM. Consumer attitudes and behaviors toward more sustainable diets: a scoping review. Nutr Rev. 2023;81:1665–79.
70. Jahns L, Conrad Z, Johnson LK, Raatz SK, Kranz S. Recognition of federal dietary guidance icons Is associated with greater diet quality. J Acad Nutr Diet. 2018;118:2120–7.
71. Zhang FF, Liu J, Rehm CD, Wilde P, Mande JR, Mozaffarian D: Trends and Disparities in Diet Quality Among US Adults by Supplemental Nutrition Assistance Program Participation Status. JAMA Netw Open. 2018;1.
72. Stanaway JD, Afshin A, Gakidou E, Lim SS, Abate D, Abate KH, Abbafati C, Abbasi N, Abbastabar H, Abd-Allah F, et al. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet. 2018;392:1923–94.
73. Pollock BD, Willits-Smith AM, Heller MC, Bazzano LA, Rose D. Do diets with higher carbon footprints increase the risk of mortality? A population-based simulation study using self-selected diets from the USA. Public Health Nutr. 2022;25:1–7.
74. Spiker M, Reinhardt S, Bruening M. Academy of Nutrition and Dietetics: Revised 2020 Standards of Professional Performance for Registered Dietitian Nutritionists (Competent, Proficient, and Expert) in Sustainable, Resilient, and Healthy Food and Water Systems. J Acad Nutr Diet. 2020;120:1568-1585.e1528.
75. Guillaumie L, Boiral O, Baghdadli A, Mercille G. Integrating sustainable nutrition into health-related institutions: a systematic review of the literature. Can J Public Health. 2020;111:845–61.
76. Muñoz-Martínez J, Carrillo-Álvarez E, Janiszewska K: European dietitians as key agents of the green transition: An exploratory study of their knowledge, attitudes, practices, and training. Front in Nutr. 2023;10.
77. Geagan K: What Do Dietitians Really Think about Sustainability? Food + Planet and Today's Dietitian Release Results of 2023 Sustainability and Food Insights Survey. 2023.
78. Blackstone NT, Rodríguez-Huerta E, Battaglia K, Jackson B, Jackson E, Benoit Norris C, Decker Sparks JL. Forced labour risk is pervasive in the US land-based food supply. Nat Food. 2023;4:596–606.

Publisher's Note