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A Scoping Review of Indicators for Sustainable Healthy Diets

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Introduction: Diets are currently unsustainable in many countries as evidenced by the growing burden of malnutrition, degradation of natural resources, contributions to climate change, and unaffordability of healthy diets. Agreement on what constitutes a healthy and sustainable diet has been debated. In 2019, FAO and WHO published the Sustainable Healthy Diets Guiding Principles, defining what qualifies as a sustainable healthy diet. While valuable, these principles require measurable indicators to support their operationalization. Our scoping review aims to describe how sustainable healthy diets have been assessed in the literature since 2010.

Methods: A search for English-language articles published in peer-reviewed journals was conducted from January 2010 through February 2020 across three databases. Out of the 504 articles initially identified, 103 articles were included. Metadata were extracted from each article on: publication year, country of study, study aims, methods, main data sources, indicators used to assess sustainable healthy diets, reported indicator strengths or limitations, and main study findings. A qualitative content analysis identified major conceptual themes across indicators and their frequency of use.

Findings: From the 103 empirical articles included in our review, 57.3% were published after 2017. Most studies were carried out in high-income countries (74%). Approximately 42% of the articles assessed the sustainability of diets using solely health and environmental indicators; <25% assessed the sustainability of diets across health, environmental, and sociocultural aspects of sustainability. We found a substantial number of unique indicators used for assessing health ($n = 82$), environmental ($n = 117$), and sociocultural ($n = 43$) aspects of diets. These indicators covered concepts related to health outcomes, aspects of diet quality, natural resources, climate change, cultural acceptability, and cost of diets. The preponderance of indicators currently used in research likely poses challenges for stakeholders to identify the most appropriate measures.

Conclusion: Robust indicators for sustainable healthy diets are critical for understanding trends, setting targets, and monitoring progress across national and sub-national levels. Our review highlights the geographical imbalance, the narrow focus on health and environmental aspects, and the lack of common measures used in research. Measures registries could provide the decision-support needed by stakeholders to aid in the indicator selection process.

Keywords: sustainable healthy diets, indicators and metrics, sustainable diets, dietary assessment, sociocultural indicators, environmental indicators, dietary indicators

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INTRODUCTION

The Unsustainability of Current Diets

Combatting malnutrition in all its forms—including undernutrition, micronutrient deficiency, overweight, and obesity—and reducing the burden of diet-related non-communicable diseases (NCDs) are two of the major global challenges of the twenty-first century. The recent State of Food Security and Nutrition report confirms the rise in prevalence of global hunger over the past 5 years (FAO, 2020). Undernutrition for children aged <5 years persists in the forms of stunting (144 million), wasting (47 million), and underweight (88 million) (UNICEF/WHO, 2020; WHO, 2020). At the same time, ∼2 billion adults and 340 million children (aged 5–19 years) are currently overweight or obese (Abarca-Gómez et al., 2017).

Malnutrition has serious, costly, and long-lasting health, social, and developmental impacts for individuals and countries. During childhood, undernutrition is associated with higher risks of infectious diseases, lower cognitive scores, and poor school achievement (Adair et al., 2013; Black et al., 2013; Sacchi et al., 2020). Obesity also poses immediate health risks (Lloyd et al., 2012; Narang and Mathew, 2012; Cote et al., 2013; Mohanan et al., 2014; Bacha and Gidding, 2016; Di Bonito et al., 2018) and often persists into adulthood with increased risk of non-communicable diseases such as coronary heart disease, stroke, type 2 diabetes, and several types of cancer (Guh et al., 2009; Lauby-Secretan et al., 2016). Micronutrient deficiencies, which can occur across age and body weight categories, are a particular concern for women of reproductive age and young children (Black et al., 2013; Zimmermann, 2016). Malnutrition also carries large direct and indirect costs to individuals and national economies as it has direct impact on human capital. While the causes of malnutrition are complex, poor diet is a leading contributor to the global burden of diet-related diseases and is responsible for more deaths than any other risk factor globally (Afshin et al., 2019). Suboptimal diets are generally low in fibers, fruits, vegetables, legumes, whole grains, nuts and seeds, milk, seafood, calcium, and healthy fats (omega 3 fatty acids, polyunsaturated fatty acids) and high in *trans*-fatty acids, sodium, red or processed meat, and sugar-sweetened beverages (Afshin et al., 2019).

Beyond delivering suboptimal and inequitable population health outcomes, current food consumption patterns place a significant strain on land, water, air, and other natural resources. Agricultural production is responsible for 40% of global land use and 70% of fresh water withdrawals (Foley et al., 2005; Molden, 2013). The conversion of natural ecosystems to cropland and pasture land is one of the greatest drivers of biodiversity loss (Tilman et al., 2017). The over-application and misuse of fertilizers results in nitrogen and phosphorus runoff, fueling the eutrophication of lakes, rivers, and coastal areas and creating "dead zones" (Diaz and Rosenberg, 2008). Current consumption patterns contribute to climate change, with global food systems accounting for up to 29% of global greenhouse gas emissions (GHGE) (Vermeulen et al., 2012). Although malnutrition in all its forms is the largest cause of lost health in the world (Swinburn et al., 2019), the health effects of climate change will considerably compound these health challenges in the near future through impacts on crop yields, nutrient quality of foods, and changing land and ocean temperatures (Myers et al., 2017).

Healthy diets remain unaffordable for many people in almost every region of the world (FAO, 2020). Nutrient-dense foods are often more expensive than starchy staples and foods high in sugar and fat, especially in low-income countries (Headey and Alderman, 2019). At the same time, current production levels of nutrient-dense foods like fruits and vegetables are inadequate to meet minimum global dietary recommendations for the global population (Mason-D'Croz et al., 2019). Meanwhile, 32% of food produced globally is lost or goes to waste (FAO, 2011). At the same time, food choices and food-related behaviors are deeply connected to social and economic expressions of identity, gender, religion, preferences, and cultural meaning (Monterrosa et al., 2020). For example, in many societies food symbolizes social standing, where foods consumed by the affluent symbolize superiority while less-prestigious foods may be associated with poverty (Cloete and Idsardi, 2013; Monterrosa et al., 2020). Religious or spiritual views can determine which foods are good or bad, holy or unholy, clean or dirty (Fieldhouse, 2013). The sustainability of any diet is influenced by sociocultural factors such as conditional food preferences, attitudes, values, social structures, cultural practices, and assets just to name a few (Monterrosa et al., 2020). Any attempt to transition toward more sustainable healthy diets must take into account the sociocultural factors that underpin consumption patterns.

The History of Sustainable Healthy Diets

The term "sustainable diets" is not new. It was first introduced in the literature in Gussow and Clancy (1986), where the authors argued the importance of optimizing individual diets for both human health and the protection of natural resources (Gussow and Clancy, 1986). The concept obtained little attention in the ensuing years, as the global community focused on reducing hunger, undernutrition, and food insecurity. This focus led to policies centered around increasing agricultural industrialization, production intensification, and food globalization, often with little consideration for how such policies may exacerbate existing inequalities or negatively impact natural resources (Lang, 2010). In 2010, a widely accepted definition of sustainable diets was coined stating, "Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to a 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; while optimizing natural and human resources" (Burlingame and Dernini, 2012). This definition broadened the understanding of sustainable diets to be more comprehensive, encompassing aspects beyond human health and natural resources alone.

In 2014, the Second International Conference on Nutrition highlighted the challenges and urgency of transforming food systems to deliver healthy diets in a sustainable manner given the growing double burden of malnutrition (CIHEAM/FAO, 2015). Conceptual frameworks were developed showing the relationship between food systems and nutrition (HLPE, 2017). Calls for transforming food systems to become more sustainable and capable of ensuring healthy diets began to be globally embraced. The role of diets as a lever for sustainability was highlighted in many publications (Johnston et al., 2014; Gustafson et al., 2016; Downs et al., 2017). However, this role was often ill-defined; at times, it focused only on a single issue, while at other times it included multiple environmental, economic, and societal goals. The lack of agreement by countries on what constitutes healthy diets and more so on what constitutes healthy diets that are sustainable led the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) to produce the Sustainable Healthy Diets Guiding Principles in 2019. While the previous definition included health considerations, in its application, economic and environmental goals of diets were often given preeminence. This new definition placed health at the forefront of consideration, while still underscoring the need to consider all aspects. The report defined sustainable healthy diets as, "dietary patterns that promote all dimensions of individuals' health and wellbeing, have low environmental pressure and impact, are accessible, affordable, safe and equitable, and are culturally acceptable" and includes 16 principles grouped under three aspects of sustainability: health, environmental and sociocultural that must be considered together for achieving sustainable healthy diets (FAO WHO, 2019).

Challenges to Quantifying Sustainable Healthy Diets

The 16 guiding principles of sustainable healthy diets aim to provide flexible guidance to countries for policy and program implementation, taking into account different local contexts. However, for them to be operationalized, the values laid out in the 16 guiding principles must correspond to measures capable of analyze trends, set targets, and monitor progress at national or subnational levels. Clear indicators and methods for measuring the different aspects of sustainable healthy diets are necessary for (1) building the evidence base to support guidelines and policies for the promotion of sustainable healthy diets and (2) monitoring and evaluating progress toward national and subnational targets for transitioning toward sustainable healthy diets. In order to build a compendium of indicators for sustainable healthy diets, there is a need to identify and describe the measures currently being used in research on sustainable healthy diets. Previous literature reviews have partially examined measurements of sustainable diets, but fell short of investigating how the concept of sustainable diets was defined by researchers and did not report on any strength or limitation of proposed measures (Jones et al., 2016; Eme et al., 2019). Our goal was to carry out a literature review of empirical studies to describe how sustainable healthy diets have been defined and measured in the research literature. This review was designed to address the questions: (1) how have sustainable healthy diets been defined in the scientific literature since 2010 and (2) what range of indicators is currently in use for assessing sustainable healthy diets and with what frequency are these indicators being used?

METHODS

Study Design

Given the complexity of sustainable healthy diets and the vast number of indicators proposed and reported in the academic literature, a modified scoping review design was adopted (Peters et al., 2015). As opposed to systematic literature reviews, which seek to answer a very specific set of questions, scoping reviews aim to determine what kind of evidence (quantitative or qualitative) is available on a particular topic and synthesize these data through mapping or charting. Since scoping reviews are broader in nature, they can be particularly useful for bringing together evidence from heterogeneous sources. Existing indicators of sustainable healthy diets reported in peer-reviewed literature were compiled and categorized. The indicator compilation was conducted between March and August 2020.

Literature Search Strategy and Study Selection

A search for English-language articles published in peer-reviewed journals between January 2010 and February 2020 was performed using the electronic databases PubMed, Science Direct, and Web of Science. The start date for the search was based on the year the definition of sustainable diets was published (Burlingame and Dernini, 2012). The search was undertaken with a uniform set of search terms, along with Boolean logic modified to the select database (**Supplementary Table 2**).

Following recommended protocols for scoping reviews, at least two reviewers were involved in the abstract and full-text screening of each article in order to minimize reporting bias (Peters et al., 2015). The database search resulted in 504 articles. After removing duplicates, 443 articles remained. The initial round of title and abstract screening yielding 199 eligible articles. A further round of full-text screening resulted in 103 original articles for inclusion in this review (**Figure 1**). Any conflicts between independent reviewers regarding the eligibility of articles for inclusion were resolved through discussions within the review team until consensus was reached. Criteria for exclusion are described in **Supplementary Table 3**.

Data Collection and Analysis

Papers included in this review were analyzed and data were extracted for details on the following variables: publication year, country of study, study aims, methods, main data sources, definitions of sustainable diets, indicators used to assess sustainable diets, reported justifications and limitations of select indicators by the study authors, and main study findings. Data extraction was completed by one of three reviewers for each article. Quality assurance checks on extracted data were completed by a second reviewer on approximately 75% of included articles to limit data extraction errors. Indicators were identified based on the data sources used and the empirical analysis undertaken as part of each study. For the purpose of this review, we defined "concepts" as the abstract phenomena or idea that was being studied while "indicators" were defined as quantitative or qualitative measures used to communicate information on that particular phenomena or idea. Variables, or

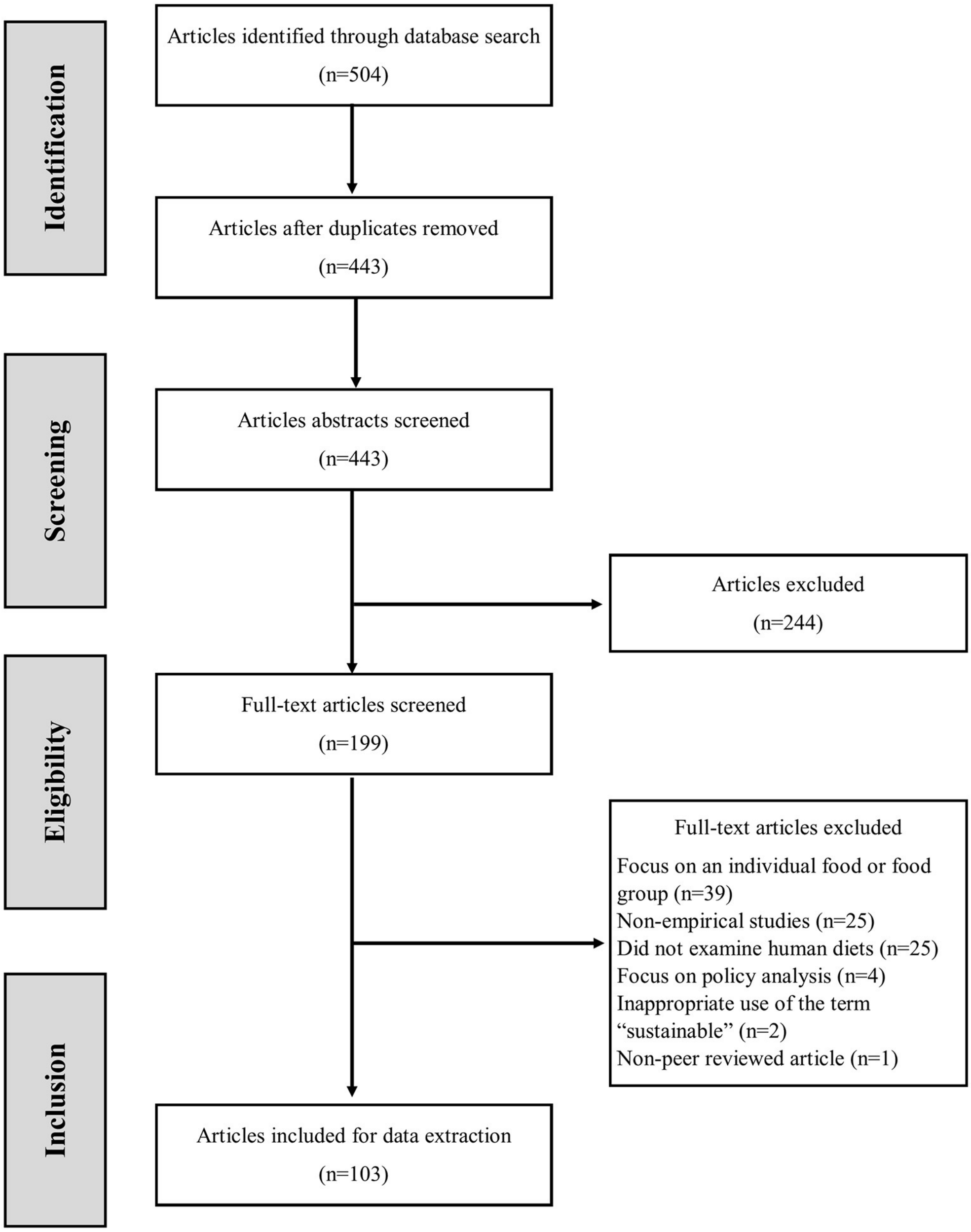

FIGURE 1 | PRISMA diagram of article identification and selection for qualitative analysis.

the value that an indicator takes on and its scale of measurement, were not extracted as part of our review. As part of the data extraction tool, all indicators were mapped to one of the three main aspects used to define sustainable healthy diets (i.e., health, environmental, and sociocultural aspects). All data were collected, stored, and analyzed in Microsoft Excel.

Given the heterogeneity of study designs related to sustainable healthy diets, the indicators used in assessing the sustainability of diets were evaluated on a qualitative and descriptive basis, rather than quantitatively. Following data extraction and cleaning, a qualitative content analysis was undertaken to identify major conceptual themes across indicators. Indicators were further grouped based on semantic similarities in order to synthesize the results presented below. The frequency of use for each indicators was calculated by conceptual theme. The total number of unique or non-repeating indicators was also calculated to provide insight on the range of diverse measurements being used by researchers. In line with standard scoping review practices, a formal assessment of the methodological quality of included studies was not performed (Peters et al., 2015). Therefore, although the main findings of each study are presented, weighing the quality of evidence for each study was outside the scope of this review.

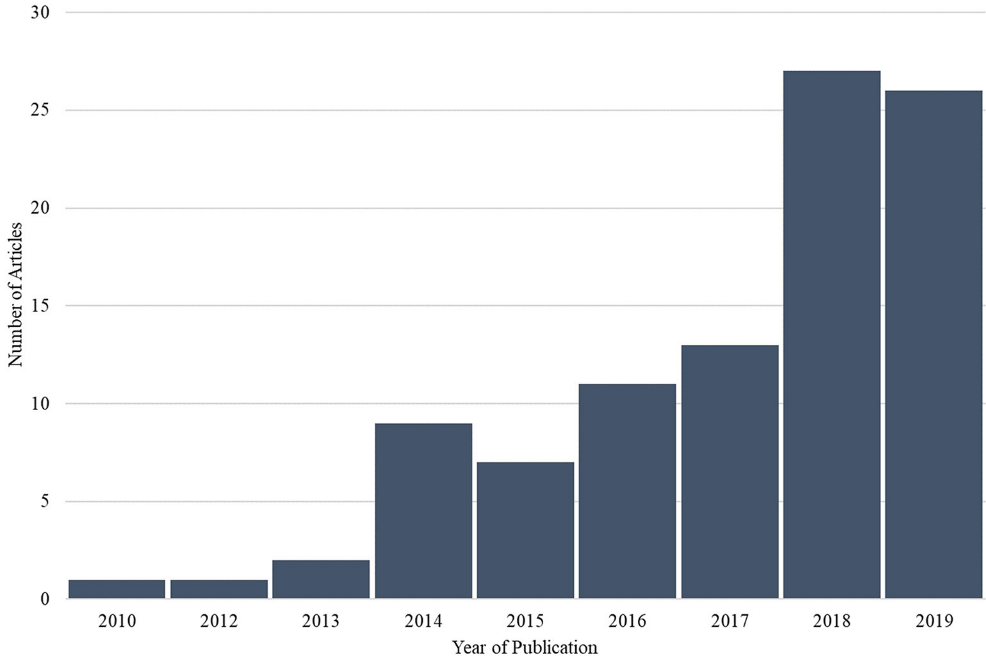

FIGURE 2 | Distribution of articles by year of publication, 2010–2019. Six articles identified between January–February 2020 are not pictured in the figure above, but were included in the scoping review.

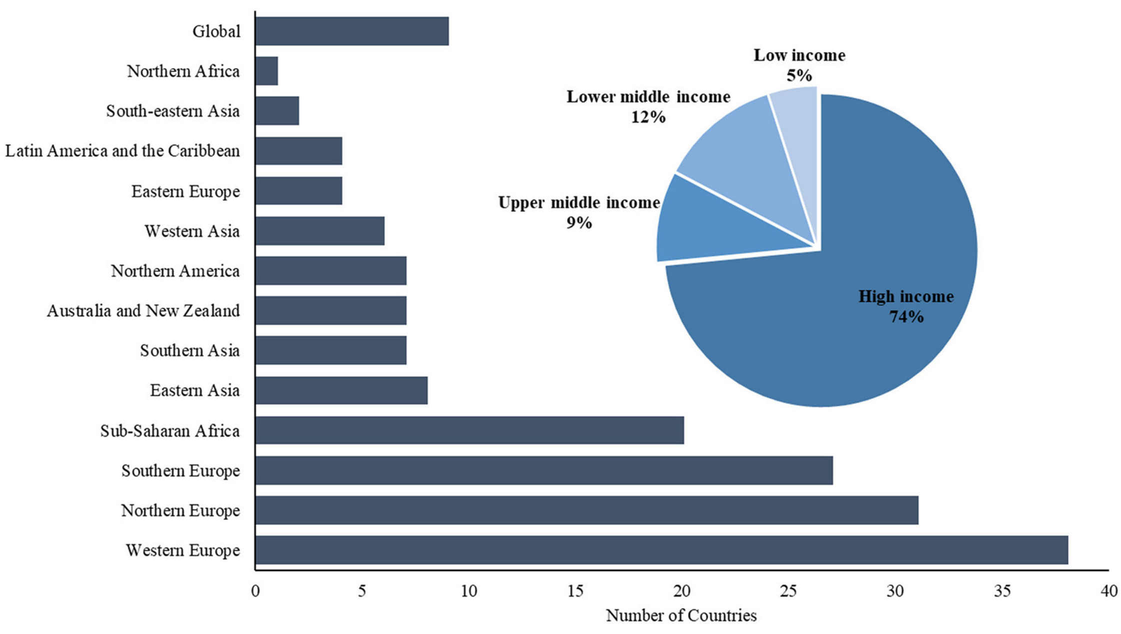

FIGURE 3 | Distribution of countries contributing data to included articles, by sub-region and income group. Sub-Region classification is based on the United Nations Statistics Division classification (UNSD, 2020). Income group classification is based on the World Bank's 2020 fiscal year classification (World Bank Country Lending Groups, 2020). The x axis shows the number of countries that contributed data to the included studies from the sub-region shown. Studies were classified as global if they included data from >36 countries.

TABLE 1 | Health indicators by concept measured and frequency of use in the scoping review.

Health indicators (n = 143)			
Concept		**Frequency count, *n***	**Examples**
Health outcomes		26	Avoided DALYs from cardiovascular disease, diabetes, and/or cancer; avoided premature death; prevalence of under-five childhood stunting (%); prevalence of under-five underweight (%)
Diet quality	Nutrient adequacy	22	% Population share with adequate nutrients; adequacy ratio for individual macro- and micronutrients; mean adequacy ratio; prevalence of inadequate micronutrient intake
	Nutrient density	16	NRD9.3 Index; NRF9.3 Index; density of overconsumed nutrients; Nutrient Balance score
	Moderation	12	Animal-to-plant energy ratio; animal-to-plant protein ratio; discretionary energy intake; excess red and processed meat consumption; mean excess ratio
	Diversity	9	Child Diet Diversity score; Diet Diversity Score; dietary species richness; Functional Diversity score
	Safety	1	Contaminant content of food
	Multiple concepts	47	Healthy Eating Index; PANDiet score; adequate total energy, macronutrient, and micronutrient intake; Diet Quality Index; SAIN:LIM ratio
Diet quantity		4	Non-discretionary energy intake; total energy availability; total energy intake
Other		6	Ratio of fruit and vegetable availability to recommended consumption; bio-conversion factors for food

TABLE 2 | Environmental indicators by concept measured and frequency of use in the scoping review.

Environmental indicators (n = 262)		
Concept	**Frequency count, *n***	**Examples**
Greenhouse gases	77	GHGE; carbon footprint; climate impact; food production GHGE; global warming impact; global warming potential; landfill GHGE; total CO_2 emissions
Water use	47	Blue water scarcity footprint; blue water footprint; freshwater use; gray water footprint; green water footprint; total water footprint; water consumption; water use
Land use	36	Land use; cropland use; ecological footprint; land occupation; land footprint; nature occupation
Toxicology	16	Respiratory inorganics; ecotoxicity; human toxicity; particulate matter
Energy use	16	Energy use; cumulative energy demand; energy consumption; fossil resource scarcity; non-renewable energy
Eutrophication	11	Eutrophication potential; freshwater eutrophication; marine eutrophication; marine eutrophication potential
Reactive nitrogen	9	Nitrogen application; nitrogen footprint; ammonia emissions; nitrogen loss
Acidification	9	Acidification; acidification potential; air acidification; terrestrial acidification potential
Ozone depletion	7	Ozone layer depletion; photochemical ozone creation potential; stratospheric ozone depletion
Biodiversity	5	Biodiversity damage potential; extinction rate; biodiversity loss from land use; regional biodiversity impacts due to land use occupation
Food waste	5	Food waste rate; household food waste; consumer-level food loss and waste
Phosphorus use	4	Phosphorus application; phosphorus cycle; phosphorus use
Other	20	Partial ReCiPe score; sustainability score; biosphere integrity; fish stock remaining; forest cover loss; GHGE-Land Use score; environmental impact score

RESULTS

This scoping review included 103 empirical studies, with the majority of these articles published after 2017 (57.3%) (**Figure 2**). The vast majority of studies were focused in high-income countries (74%), particularly Western Europe, Northern Europe, and Southern Europe (**Figure 3**). A summary of the 103 articles included in this review are listed in **Supplementary Table 1**. Indicators used to assess the sustainability of diets in each article were mapped to one of the three main aspects used to define sustainable. An overview of the health, environmental, and sociocultural indicators used for assessing the sustainability of diets can be found in **Tables 1–3**, respectively.

Definitions of Diets' Sustainability

Twenty-nine articles (28% of sample) referred to or cited the 2010 definition of sustainable diets. Sustainable diets were not explicitly defined in 60 articles (58% of sample). The remaining articles (n = 14; 14% of sample) offered an alternative definition of sustainable diets. Alternative definitions often considered only two out of the three aspects of sustainable healthy diets. Alternative definitions more frequently focused on health and environmental aspects, and neglected to mention the sociocultural aspect. **Supplementary Table 4** provides representative quotes for alternative definitions of sustainable diets proposed in the literature as found by this scoping review.

Methods and Data Sources Used Across Studies

Of the 103 articles included in the current review, 44 examined observed diets only (i.e., based on empirical data

TABLE 3 | Sociocultural indicators by concept measured and frequency of use in the scoping review.

Sociocultural indicators ($n = 59$)		
Concept	**Frequency count, *n***	**Examples**
Cultural acceptability	10	Acceptability; cultural acceptability; culture deviation index; respect for current dietary habits; social and cultural acceptability of diets
Animal welfare	3	Animal life years suffered; loss of animal lives; loss of morally adjusted animal lives
Satisfaction	3	Appreciation of meal; palatability; tastiness of meal
Attitudes	1	Environmental attitudes
Food security	1	Provision of adequate nutrition for a fair number of people
Cost of diets	24	Cost of diets; cost of meal; consumer costs; food expenditure; price of food; share of budget dedicated to food purchase; diet affordability; cost of nutrient adequacy
Environmental costs	7	Cost of environmental impact of diet; cost benefits attributable to environmental improvements; cost of GHGE embodied in food consumption; cost of environmental benefits
Health costs	4	Cost benefits attributable to health improvements; cost per DALY saved; obesity-related health expenditure; Health sector costs attributable to inadequate fruit and vegetable consumption and elevated BMI
Productivity costs	1	Productivity costs attributable to inadequate fruit and vegetable consumption and elevated BMI
Other	5	Accidents among farm workers; frequency of consumption of ready-made products; number of working hours for farmers; place of food purchase

and representative of actual population diets). Eighteen articles examined modeled diets only (i.e., those consistent with evidence-based recommendations or hypothetical scenarios) and 39 articles examined both observed and modeled diets. Multi-objective optimizations modeling, which was used in 12 articles, was one of the most common modeling methods employed. Multi-objective optimization modeling, also known as linear programming, is a mathematical technique used to minimize or maximize a linear function, depending on a series of defined constraints. It is commonly used in diet optimization studies. For the studies that aimed to improve diet-related health outcomes, most assumed health improvements would be achieved through adherence to evidence-based dietary recommendations. However, seven studies explicitly estimated improvements in health outcomes associated with different dietary scenarios. Dietary data came largely from national health and food consumption surveys collected at the individual level (e.g., Australian Health Survey, the Danish National Dietary Survey, and the French NutriNet-Santé study), data collected at the household level through household consumption and expenditure surveys (HCES), and data available at the national level through Food Balance Sheets (FAOSTAT).

Methods used for evaluating the environmental impacts of diets varied across studies. Life cycle assessment (LCA) was used in the majority of studies. LCA is a quantitative modeling approach used to estimate environmental impacts across a product's life cycle (Garnett et al., 2016). The system boundaries of LCAs can differ, with the most comprehensive boundaries being "cradle to grave." While the systems boundaries varied by study, nearly all began with the "cradle" or the raw materials needed for agricultural inputs. Many studies stopped short of undertaking a full life cycle analysis through the "grave" or the end point where a final product is disposed; instead, limiting systems boundaries to production stages such as "cradle to farm gate" or "cradle to retail." Input-output analysis was used in five studies to estimate the environmental or economic impacts of diets. Input-output analysis is an economic technique used to trace economic activity through complex supply-chain networks and estimate immediate and indirect impacts of systemic shocks (Boylan et al., 2020). Environmental data came largely from LCA databases, LCA studies, previously published peer-review literature, national environmental or agricultural database such as those maintained by ministries of agriculture, and global databases, for example the Water Footprint Network.

Sociocultural data relied largely on household consumption and expenditure surveys, cost of living surveys, market research data from sources like Kantar world panel purchase database (Consumer Panels, 2021), and price audits of local food environments. Other sociocultural data came from study-specific surveys on attitudes and practices or taste preferences, or were derived from food consumption surveys.

Concepts and Indicators of Sustainable Healthy Diets

Forty-two percent of articles in our review assessed the sustainability of diets using both health and environmental indicators. Relatively few articles (32%) assessed the sustainability of diets using any sociocultural indicators. Less than 25% of the articles assessed the sustainability of diets across all three aspects (**Figure 4**).

Health Concepts and Indicators

Seventy-five articles (72% of the sample) assessed the health aspects of diets. A total of 143 health indicators were identified within these articles, including 82 unique health indicators (**Supplementary Table 5**). Indicators were coded to concepts related to diet quality, diet quantity, and health outcomes.

While no universal definition for diet quality exists, the concept of diet quality is frequently examined through parameters such as nutrient adequacy, variety or diversity, moderation, nutrient density, and food safety (Alkerwi, 2014). Adequacy refers to the attainment of dietary energy, macro-, and micronutrients appropriate to age, sex, disease status, and physical activity level for a healthy life. Adequacy was one

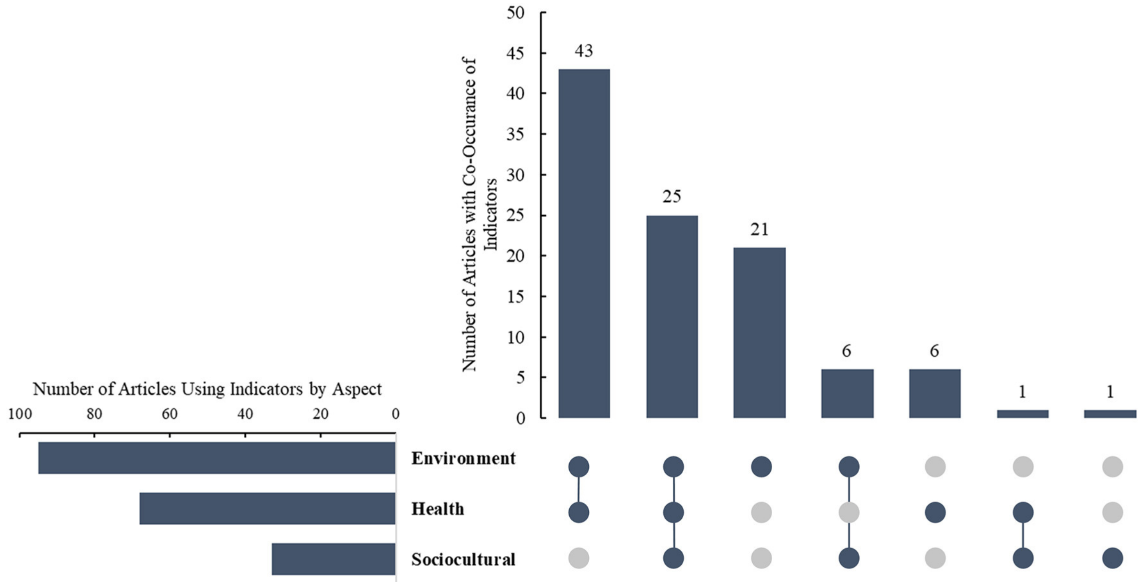

FIGURE 4 | UpSet plot of articles using indicators to assess the sustainability of diets across three aspects. The left bar plot represents the total number of articles using health or nutrition, environmental, sociocultural, or economic indicators. Every possible intersection is represented by the bottom plot, and their occurrence is shown in the top bar plot.

of the more frequently assessed health concepts ($n = 22$; 15% of the health indicators) and was often measured through indicators that determined adequate total energy, macronutrient, and micronutrient intake based on national and international recommendations (**Table 1**). Nutrient density reflects the nutrient content of a given food relative to its total energy content. Approximately 11% ($n = 16$) of the health indicators measured nutrient density, with the Nutrient Rich Food Index and the Nutrient Rich Diet Index (Fulgoni et al., 2009; Van Kernebeek et al., 2014) being the most frequently used. Moderation refers to avoiding or limiting foods that contribute to an excess risk to disease. Of the indicators used to assess moderation ($n = 12$; 8% of the health indicators), most focused on the total amount or proportion of animal source foods or animal source protein in the diet. Diversity reflects the consumption of a variety of foods across and within food groups over a given period of time. The concept of diversity was assessed through indicators such as the Diet Diversity Score, the Minimum Dietary Diversity indicator for young children, and the Functional Diversity score (Steyn et al., 2006; Luckett et al., 2015; WHO., 2021). Food safety is another parameter of diet quality and includes both foodborne disease and harmful hazards such as toxins and food contaminants. Food safety was found only once in our review of indicators. The concept of diet quality was most frequently assessed through composite indicators, which measured multiple concepts of diet quality previously mentioned (e.g., adequacy, moderation, diversity, etc.) ($n = 47$; 33% of the health indicators). Of the indicators which assessed multiple concepts of diet quality, the most frequently used indicators where healthy eating indices based on national dietary guidelines (e.g., Brazilian Healthy Eating Index, the DHD15-Index, and the Healthy Eating Index), Mediterranean Diet Scores, and the PANDiet score (Trichopoulou et al., 2005; Guenther et al., 2008; Previdelli et al., 2011; Verger et al., 2012; Naja et al., 2015; Looman et al., 2017). Other frequently used indicators included total energy and macronutrient intake and measures of adequacy (such as total energy, macronutrient, micronutrient, fruit and vegetable intake, etc.) based on national or international recommendations (both nutrient- and food-based).

Other health indicators related to concepts of diet quantity and health outcomes. Diet quantity is a concept referring to the total dietary energy supply or intake. Diet quantity was rarely assessed ($n = 4$; 3% of health indicators), but when it was, it focused on energy supply or availability and energy intake. Finally, health outcomes were the second most frequently assessed health concept ($n = 26$; 18% of health indicators). Nearly all health outcomes were morbidity or mortality indicators for chronic diseases such as coronary heart disease, stroke, type 2 diabetes, and certain cancers. The most frequently used health outcome indicators were Disability Adjusted Life Years (DALYs) from cardiovascular disease, diabetes, and/or cancer. Other health-related indicators included prevalence of underweight and stunting for children <5 years of age, avoided premature deaths, reduced DALYs, years of life saved, and Health Gain Score (Van Dooren et al., 2014).

Strengths and Limitations of Health and Nutrition Indicators

The authors of the included articles reported several strengths and limitations of different health indicators. In the case of nutrient adequacy, indicators were frequently justified by researchers because they were based on national or international guidelines for optimal nutrient intake (Tyszler et al., 2016; Kramer et al., 2017; Lachat et al., 2018; Rao et al., 2018), however, some articles noted that bioavailability of nutrients may not have been considered (de Ruiter et al., 2018) and even when taken into account, bioavailability can vary substantially with other individual- and household-level factors (Rao et al., 2018). Indicators of nutrient density, such as the Nutrient Rich Food Index, were selected because they had been shown to track diet quality more effectively compared with other indices and because they had been validated in prior studies (Castañé and Antón, 2017; González-García et al., 2018). A noted strength of the Nutrient Rich Diet Index was that because it is not scaled to energy intake, it allows for comparison between diets with different caloric content, therefore, easing the comparisons across the literature (Esteve-Llorens et al., 2020). While indices like the Nutrient Rich Diet Index have been validated, one study noted that nutrient density scores are less "transparent" making results highly dependent on how the score is constructed and may be difficult to interpret (Röös et al., 2015). Diet diversity indicators among children were justified as proxy indicators of diet quality associated with nutrient adequacy of children's diets and based on prior validation studies among children in the article's age range (Galway et al., 2018). Among indicators for multiple components of diet quality, the PANDiet score was justified because it is based on adherence to national nutrition and health recommendations and tracts with other indicators of nutritional quality among French and U.S. national health and nutrition surveys (Masset et al., 2014b; Lacour et al., 2018; Seconda et al., 2018, 2019). The DHD15-Index, an example of one specific healthy eating index used, was justified because it reflects adherence to the Dutch food-based dietary guidelines and is also a measure of health since it is negatively correlated with mortality and cardiometabolic risk factors (Van Dooren et al., 2018b; Vellinga et al., 2019). Similar to the DHD15-Index, other composite indices such as healthy eating indices, the Health Score, and the Diet Quality Index were justified because they were based on national dietary guidelines (Carvalho et al., 2013; Wrieden et al., 2019) and assessed overall diets beyond single nutrients (Rose et al., 2019), an important factor for the reduction of obesity and diet-related non-communicable diseases (Van Dooren et al., 2014).

Environmental Concepts and Indicators

Ninety-five articles (92% of the sample) assessed the sustainability of diets using environmental indicators. A total of 262 environmental indicators were identified within these articles, including 117 unique environmental indicators (**Supplementary Table 5**). Indicators were coded to concepts related to natural resources (e.g., water use, land use, biodiversity, etc.) and climate change (e.g., greenhouse gases, ozone depletion, etc.)

Indicators related to greenhouse gases were the most frequently utilized out of all the environmental concepts ($n = 77$; 29% of environmental indicators) (**Table 2**). Greenhouse gases includes gases such as carbon dioxide, methane, and nitrous oxide, which lead to global warming. The most frequently used indicators related to greenhouse gases included GHGEs, carbon footprint, and global warming potential. Water use was the second most frequently assessed environmental concept of diets ($n = 47$; 18% of environmental indicators). Water use quantifies the amount of water used to produce various goods and services. Frequently used indicators of water use included total water use and water footprint, blue water use and blue water footprint, green water use and green water footprint, freshwater use, and water scarcity footprint. Land use was another frequently assessed environmental concept for diets ($n = 36$; 14% of environmental indicators) that refers to the designated use of land by humans such as cropland, grazeland, and forest management. Commonly used indicators for assessing land use included total land use, land occupation, cropland use, ecological footprint, and nature occupation. Energy use ($n = 16$; 6% of environmental indicators) was frequently assessed through total energy use, energy consumption, cumulative energy demand, and non-renewable energy. Toxicology refers to the assessment of toxic substances in the environment and was frequently assessed through indicators such as ecotoxicity, human toxicity, particulate matter-related emissions, and respiratory inorganics ($n = 16$; 6% of environmental indicators). Eutrophication refer to excess levels of nutrients (e.g., nitrogen and phosphorus) in a body of water, while acidification refers to excess acid in the soil, water, or air. Frequent indicators for eutrophication included eutrophication potential, freshwater eutrophication, and marine eutrophication. Acidification was most often assessed through acidification potential and air acidification. Reactive nitrogen includes all the biological, chemical, and radiative active nitrogen compounds in the atmosphere. Nitrogen application and nitrogen footprint were the most frequently used indicators for assessing reactive nitrogen. Ozone depletion refers to a decline in the level of ozone gas as a result of its breakdown into oxygen. Ozone depletion was frequently measured through indicators such as ozone layer depletion and photochemical ozone depletion. Biodiversity refers to the variety and variability of living organisms in a given area. Biodiversity was most commonly assessed through species loss from land use followed by biodiversity damage potential and extinction rate. Indicators for food waste and phosphorus use, while infrequent, were leveraged in a few articles. Other common indicators include those that combined multiple environmental concepts such as the ReCiPe score (Huijbregts et al., 2017) which can include up to 18 environmental indicators. Other composite environmental indicators included the GHGE-Land Use score and sustainability scores (Van Dooren et al., 2014; van Dooren and Aiking, 2016; Fresán et al., 2018).

Strengths and Limitations of Environmental Indicators

The authors noted several strengths and limitations of environmental indicators in the included articles. Regarding greenhouse gases, authors frequently noted that GHGE can be used as a proxy for other environmental impacts since it is often highly-correlated with other phenomenon such as eutrophication, acidification, land use, and other environmental indicators (Masset et al., 2014b, 2015; Van de Kamp and Temme, 2018; Van de Kamp et al., 2018; Van Dooren et al., 2018b). Conversely, other articles which employed GHGE noted that other environmental indicators such as biodiversity loss and water use are important environmental impacts that still need to be taken into account (Masset et al., 2014b; Arrieta and González, 2018), thus suggesting that GHGE alone is insufficiently capture environmental impact. Carbon footprint was often justified due to its widespread use in studies on dietary patterns (Lukas et al., 2016; Esteve-Llorens et al., 2019b, 2020). However, some articles noted the selected systems boundaries (e.g., cradle-to-gate, cradle-to-store, cradle-to-grave) can significantly impact carbon footprint estimates (Esteve-Llorens et al., 2019a, 2020). The strengths and limitations of water use varied considerably depending on the type of water use assessed. The efficient use of green water can decrease reliance on blue water and the inclusion of green water in water resource management is now frequently recommended (Vanham et al., 2016; Kim et al., 2020). One article noted that water footprint, when used only in its aggregate form (summed total of blue, green, and gray water), can be misleading due to the significant tradeoffs that exist between blue and green water, and their substantial differences from gray water. Moreover, water footprint represents only the quantity of water used without considering how it relates to environmental impact (De Laurentiis et al., 2019). Water scarcity footprint was a preferred indicator in some articles because it considers the different impacts water use has according to a particular region (Hess et al., 2015; De Laurentiis et al., 2019; Ridoutt et al., 2019). A number of strengths were also mentioned with regard to combined environmental indicators. Because GHGE are one of the most commonly accepted indicators for assessing environmental impacts of dietary patterns and because land use and changes in land use are good proxies for biodiversity, the GHGE-Land Use score was considered a strong indicator by one article (van Dooren and Aiking, 2016). Similarly, a sustainability score derived from GHGE and land use, was justified in another article because the score incorporated the two most important contributors to environmental impacts of agricultural production (GHGE and land use), along with fossil fuels (Van Dooren et al., 2014). While environmental indicators like GHGE, land occupancy, and fossil energy can individually contribute to sustainability assessments, tradeoffs exist between them. The strength of using a ReCiPe or partial ReCiPe score, which includes these three indicators and up to 15 others, is that it avoids the potentially undesirable negative effect of assessing one indicator alone (Kramer et al., 2017).

Sociocultural Concepts and Indicators

Thirty-three articles (32% of the sample) assessed the sustainability of diets using sociocultural indicators. A total of 59 sociocultural indicators were identified within these articles, including 43 unique sociocultural indicators (**Supplementary Table 5**). Indicators were coded to concepts related to cultural acceptability, meal satisfaction, animal welfare, and economic costs.

The main sociocultural concepts measured were the cost of diets ($n = 24$; 41% of sociocultural indicators), cultural acceptability ($n = 10$; 17% of sociocultural indicators), and environmental costs ($n = 7$; 12% of sociocultural indicators) (**Table 3**). Of the 24 indicators related to costs of diets, most focused on the total cost of diets, cost of meals, cost of recipes, or cost of nutrients. Four indicators focused on the affordability of diets, such as the share of household budget dedicated to purchasing food or the ratio of food expenditure to per capita income. Cultural acceptability was most frequently measured as a minimal departure from the current diet. Indicators of environmental costs included cost benefits related to environmental improvements, the cost of total environmental impact of diets, and the cost of GHGE, total energy, and total water embodied in food consumption. Other concepts measured included animal welfare, satisfaction, and health costs. Animal welfare was assessed using animal life years suffered, loss of animal lives, and loss of morally adjusted animal lives. Satisfaction was measured through the appreciation of meals, palatability (based on food portions, frequency and associations), and tastiness of meals. Of the four indicators of health costs, two assessed health savings costs (cost-benefit due to health improvements and cost per DALYs saved) and the other two assessed health costs attributed to obesity.

Strengths and Limitations of Sociocultural Indicators

Relatively few strengths or limitations were cited concerning the sociocultural indicators used for assessing the sustainability of diets. Cultural acceptability of diets was not directly measured but assumed to exist in seven articles because the study designs attempted to maintain close adherence to current consumption patterns and food choices (Masset et al., 2014b; Kramer et al., 2017; Gazan et al., 2018; Rao et al., 2018; Benvenuti et al., 2019; Perignon et al., 2019; Reynolds et al., 2019). A clear limitation of this approach is that it does not guarantee that dietary shifts within a certain degree of current consumption patterns would be acceptable to consumers (Perignon et al., 2019); nor does it account for other cultural and traditional factors which can strongly influence food choice (Donati et al., 2016). When it comes to determining the cost of diets, the price of foods as an indicator can be expressed as price/kg and price/kcals (Masset et al., 2014a). One article noted that this unit of expression gives significantly different results for foods high in fat, sugar, salt, and for fruits and vegetables (Masset et al., 2014a). While one article noted that attempting to assess the affordability of diets as a ratio of diet costs relative to household income was a strength (Seconda et al., 2019), another noted it may lead to approximations in diet monetary costs assessments if there is a large time gap between when food price data and dietary intake data are collected (Seconda et al., 2018).

Cross-Cutting Indicators

A total of 11 indicators were identified during the review that cut across multiple aspects of diets' sustainability (**Table 4**), including 10 unique indicators (**Supplementary Table 5**). Out of these 11 indicators, nearly all cut across just two aspects, health and environment ($n = 8$; 72% of cross-cutting indicators). These indicators included measures such as carbon footprint per nutrient score, nutrient GHGE efficiency, and nutritional water

TABLE 4 | Cross-cutting indicators measured and frequency of use in the scoping review.

Cross cutting indicators (n = 11)		
Concept	**Frequency count, *n***	**Examples**
Cross-cutting	11	Sustainability score; people nourished per hectare; nutritional water productivity; carbon footprint per nutrient score; nutrient GHGE efficiency; Nutrient Density to Climate Impact Index

productivity. Sustainability scores and the sustainability index cut across health, environment, and sociocultural aspects.

DISCUSSION

Indicators for sustainable healthy diets—when they are measurable, robust, and verifiable—can provide critical information for policy makers, researchers, civil society, and industry. While the exact composition of diets will vary across population groups and contexts, the importance of being able to measure progress toward national or subnational targets for promoting sustainable healthy diets over time is critical.

Our review found that while 28% of the 103 articles included referred to or cited the 2010 definition for "sustainable diets," fewer than 25% of all studies measured concepts across all three aspects of sustainability (health, environment, and sociocultural aspects). This suggests that the different aspects of sustainability are rarely comprehensively acknowledged or assessed when it comes to diets. While 92% of the studies we reviewed included any environmental indicators, a much smaller proportion (32%) included any sociocultural indicators. This imbalance is consistent with other literature reviews on measures of diets' sustainability, which found ≥70% of studies focused on human and/or environmental health outcomes and ≤30% focused on sociocultural or economic outcomes (Jones et al., 2016; Eme et al., 2019). Indicators for the sociocultural aspects of sustainability have been either under-researched or poorly established (Meybeck and Gitz, 2017). This is likely due to the fact that defining concepts and measurements within this aspect of sustainability is particularly challenging (Comerford et al., 2020).

Our review found a disproportional amount of research on the environmental and health aspects of diets, as well as the high degree of heterogeneity in indicators used across studies examining these two aspects. The breadth of indicators currently in use across research on the sustainability of diets was also consistent with the findings of recent literature reviews (Jones et al., 2016; Eme et al., 2019). This was particularly true for the diet quality concepts for which 55 unique indicators were identified (**Supplementary Table 5**). Capturing all aspects of diet quality is challenging and developing valid food- and diet-related measures of diet quality remains difficult due to the variety of dietary patterns observed globally (Alkerwi, 2014; FAO, 2020). A recent synthesis of dietary quality metrics for validating the double burden of malnutrition identified 19 dietary metrics, including 7 related to maternal and child health and 12 developed for NCDs (Miller et al., 2020). However, no metric was found to be applicable for both, and the authors expressed a need to develop novel dietary metrics for both maternal and child health and NCDs. While the authors of the review noted environmental sustainability measurements were outside the scope of their review, they highlighted the importance of incorporating environmental impacts into future dietary metrics. Another recent systematic review of diet quality metrics identified 81 different indices for diet quality (Trijsburg et al., 2019). However, only 18 were eligible for use in low- and middle-income countries and even then 16 indices failed to capture three important dimensions of diet quality (adequacy, diversity, and moderation) and the other two were country-specific. The authors emphasized the urgent need to develop both country-specific indices based on food-based dietary guidelines as well as a global diet quality index in order to allow cross-country comparisons.

While most research on the environmental effects of diets has been conducted on a small number of concepts—particularly greenhouse gases, land use, and water use—measures for eutrophication, acidification, nitrogen and phosphorus use, biodiversity, etc. are also being used. A recent literature review examined 55 different indicators for assessing the environmental impacts of diets (Van Dooren et al., 2018a). Through a selection process, the researchers concluded that two of these indicators (GHGE and land use) fulfilled most criteria necessary for addressing the environmental impact of diets. Many articles have highlighted the tradeoffs or synergies that exist across different environmental indicators (Kramer et al., 2017; Kim et al., 2020). Similar to nutritional indicators, environmental indicators are not always positively correlated; gains made through dietary changes in one indicator (such as GHGE) do not guarantee gains in other indicators (such as water use). Even within the same concept, such as water use, tradeoffs can still exist. For example, a recent systematic review on water footprints of diets underscored the importance of distinguishing between green water and blue water in addition to measuring total water footprint (Harris et al., 2020). The authors found considerable differences in blue and green water footprint of diets depending on geography, with blue water footprints being particularly high in Asia, suggesting that changes in diets alone may be insufficient to reduce these strains (Harris et al., 2020). No such constraints would have been identified had the authors examined aggregate total water footprints alone.

The breadth of indicators currently in use for measuring the different aspects of diets' sustainability may create challenges for researchers, evaluators, and policy makers to identify and select the most appropriate measures. Furthermore, the lack of common measures makes the comparison of study results across time and place difficult. This is an important consideration for monitoring progress at a national or subnational level or analyzing trends over time. The selection of indicators can be a complex and time-consuming process. It often involves an examination of the quality of proposed indicators and a process of engaging stakeholders in their selection. The criteria

TABLE 5 | Examples of criteria used for selecting sustainable healthy diet indicators (CIHEAM/FAO, 2015; Mason and Lang, 2017; Mayton et al., 2020).

Indicator selection criteria	Issue addressed
Ability to provide effective feedback to decision-makers (Mason and Lang, 2017)	Is the indicator useful for policy or program improvement efforts?
Acceptability to actors and stakeholder (Mason and Lang, 2017; Mayton et al., 2020)	Is the indicator collectively valued by all stakeholders?
Alignment with national policy priorities (Mayton et al., 2020)	Does the indicator align with national priorities for health and sustainability?
Creditability with experts (Mason and Lang, 2017)	Is the indicator deemed to be scientifically sound by subject matter experts?
Data accessibility (Mason and Lang, 2017; Mayton et al., 2020)	Is the indicator based on data that is publically available or data that could be accessed with reasonable cost-benefit ratio?
Disaggregatability or the ability to expand into details or finer scale (Mason and Lang, 2017)	Can the indicator be broken down into areas of particular interest, such as population subgroups or regional areas?
Ease of interpretation (CIHEAM/FAO, 2015)	Is the direction that the indicator should develop for improved sustainability clear?
Measurability (Mason and Lang, 2017)	Can the indicator be counted, observed, analyzed, tested, or otherwise measured?
Monitorability (CIHEAM/FAO, 2015; Mason and Lang, 2017)	Is the indicator based on data that is readily available or data that could be made readily available at a reasonable cost—benefit ratio?
	Is the indicator's data source updated within the needed time periods?
Relevance to the question being asked (CIHEAM/FAO, 2015; Mason and Lang, 2017)	Is the indicator the best measure currently available to answer the question?
Reliability (CIHEAM/FAO, 2015)	Are the indicator's underlying data collection and analysis methods consistent across time and place?
Representativeness (CIHEAM/FAO, 2015)	Can the indicator be taken to represent trends within a current population group or geography?
Sensitivity/responsiveness to change over time (Mason and Lang, 2017)	Does the indicator act as an early warning system while there is still time to prevent negative consequences?
Understandability (CIHEAM/FAO, 2015; Mason and Lang, 2017)	Is the indicator clear, simple, and unambiguous?
Validity (Mason and Lang, 2017)	Is the indicator an accurate reflection of the concept it intends to measure?

used to select indicators can (1) aid in the establishment of a shared process and vocabulary for stakeholders to select indicators, (2) reinforce the linkage between the indicators and the evaluation or research questions being addressed, and (3) help in the design, collection, storage, and retrieval of data that are clearly linked to the intended uses of findings (MacDonald, 2013). Selecting indicators for measuring the different aspects of diets' sustainability should rely on pre-defined criteria such as those listed in **Table 5**. However, this table does not reflect an exhaustive list of criteria that could be drawn from for selecting indicators. As with the selection of any indicator, there are always tradeoffs between completeness and simplicity.

If sustainable healthy diets are to be achieved, we must accelerate progress to coordinate research and collaboratively build the evidence-based needed to address diets' unsustainability. Researchers, evaluators, and policy makers need decision-support tools to aid them in selecting indicators that are most appropriate for measuring different aspects of diets' sustainability from the large number that are currently being used in research and practice. These basic tools would enhance investigators' capacity to evaluate the growing number of simulated and natural experiments aimed at promoting sustainable healthy diets by supporting the use of common measures for systematic analyses and comparisons across different studies. FAO is currently working on plans to develop one such tool—a compendium of indicators for sustainable healthy diets—based on the findings of this scoping review and input from technical experts. Additionally, measures registries, such as the one developed through the National Collaboration on Childhood Obesity Research (NCCOR) in the United States, may provide a blueprint for such a decision-support resource (National Collaborative on Childhood Obesity Research, 2020). Given the complexity of measuring the sustainability of diets, including the diversity of indicators and data sources that are drawn from, it may be beneficial to draw lessons from the development of other measures registries, surveillance catalogs, and user guides.

Limitations

Our scoping review had several limitations. First, the literature databases and the key word search strings used likely limited our results. Given the complexity of the concept of sustainability in its application to diets, there is often inconsistency in the terminology used to describe work in this area. It was beyond the time and resources of our project to carry out individual scoping reviews for each aspect of sustainability (e.g., economically sustainable diets); therefore we were parsimonious in our key word search string. Despite this limitation, our results are comparable to the findings of two recent literature reviews, even with differences in the key words and databases searched (Jones et al., 2016; Eme et al., 2019). Secondly, our exclusion criteria likely excluded some articles that contained indicators relevant to assessing diets' sustainability, such as studies focused on individual food items or food groups. While studies focusing on individual foods or food groups could be relevant to the aims of this review, many of the databases used for evaluating environmental impacts of population-, household-, or individual-level diets relied on databases, such as the EcoInvent life cycle inventory database, which have been constructed using studies on individual food items. Third, a clear geographical imbalance continues to be a limitation of the current literature. The vast majority (>70%) of studies included in our review focused on high-income countries, particularly western, northern, and southern Europe. Many of the data sources drawn from, such as national health and nutrition surveys, household consumption and expenditure surveys, or LCA databases, are not available in many low- and middle-income countries. Therefore, the indicators generated in these studies might not be applicable to low-resource contexts. This geographical bias also overlooks things like the burden of diseases and dietary patterns that tend to characterize low- and middle-income countries. Our review identified relatively few health outcome indicators for other forms of malnutrition apart from those for diet-related NCDs. Finally, while a concerted effort was made to map indicators with their corresponding aspects, not all indicators discretely fit into one domain. For example, we categorized indicators for food waste as measures of the environmental aspect of sustainable healthy diets. However, food waste indicators could also illustrate phenomena related to food safety (health aspect), social norms and consumer attitudes, or even economic constraints (sociocultural aspect). While this review aimed to describe the range of indicators currently used, during the indicator selection process it is worth considering that one indicator may partially describe many different concepts or aspects of sustainability.

CONCLUSION

Quantifiable indicators for sustainable healthy diets are critical to understanding current trends, setting targets, and monitoring progress across national and sub-national levels. Our review adds to the current body of knowledge by describing the reported strengths and limitations of frequently used indicators and how sustainable healthy diets were defined by researchers. Serious barriers to accelerating progress toward sustainable healthy diets includes the persistent geographical imbalance in research on sustainable healthy diets, the tendency to overlook sociocultural aspects of sustainable healthy diets, and the lack of common definitions and metrics used in research. Each of these barriers must be addressed in order for sustainable healthy diets to be realized. Weighing the quality of evidence and critical examination of the indicator quality was outside the scope of this review, but is the next critical step toward aiding researchers, evaluators, and policy makers in selecting appropriate indicators. Many factors have to be considered when selecting indicators for measuring diets' sustainability—including tradeoffs between and within different aspects of sustainability. These tradeoffs will require value-based decision-making that will be context specific. FAO is committed to accelerating progress on achieving sustainable healthy diets by coordinating research and collaboratively building an evidence base. Central to this commitment is the urgent need for decision-support tools to support the selection and adoption of high-performing and comparable measures across all aspects of sustainability are needed for advancing research, practice, and policy related to sustainable food systems transformation.

AUTHOR CONTRIBUTIONS

MH, GP, TB, MB-T, DQ, and FH wrote and contributed to the preparation of this manuscript. MH, GP, and FH formulated research questions explored in this review. MH, GP, DQ, and FH developed the database search string. MH, GP, and TB contributed to article screening and data extraction. MH led the analysis of the extracted data with support from MB-T, TB, and GP. All authors reviewed and contributed to the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

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