

IT'S COMPLICATED:

Understanding how Agriculture impacts the Environment

This extensive literature review study, raises the discussion that there is not a simple black and white answer to what food system has the most or least negative environmental impacts. The UN identifies 17 sustainable development goals, of which there are 14 discrete environmental areas of concern. Lead researcher, Bradley Ridoutt cites "We know a lot about greenhouse gas emissions and diets, but relatively little about other environmental concerns". He adds, "GHG emissions are important to consider, no doubt. However, we also need to look beyond GHG emissions because it is well known that efforts to reduce one environmental impact can very often exacerbate others. Current research on environmental impact lacks a holistic view", says Ridoutt.



SUSTAINABLE DEVELOPMENT GOALS



Food systems can also have positive environmental impacts that need to be considered as part of the equation. See "Plant versus Animal Protein: Why the Debate?" for more discussion on this topic - <https://thinkbeef.ca/wp-content/uploads/2018/03/Plant-versus-Animal-Protein.pdf>

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ABSTRACT:The food system is a major source of environmental impact, and dietary change has been recommended as an important and necessary strategy to reduce this impact. However, assessing the environmental performance of diets is complex due to the many types of foods eaten and the diversity of agricultural production systems and local environmental settings. To assess the state of science and identify knowledge gaps, an integrative review of the broad topic of environment and diet was undertaken, with particular focus on the completeness of coverage of environmental concerns and the metrics used. Compared with the 14 discrete environmental areas of concern identified in the United Nations Sustainable Development Goals, the located journal literature mainly addressed greenhouse gas (GHG) emissions and, to a lesser extent, land and water use. Some relevant concerns were rarely addressed or not addressed at all. In the case of GHG emissions, changes in land use and soil carbon stocks were seldom considered. This represents a disconnect between the science informing strategic climate action in the agricultural sector and the science informing public health nutrition. In the case of land and water use, few studies used metrics that are appropriate in a life-cycle context. Some metrics produce inherently biased results, which misinform about environmental impact. The limited evidence generally points to recommended diets having lower environmental impacts than typical diets, although not in every case. This is largely explained by the overconsumption of food energy associated with average diets, which is also a major driver of obesity. A shared-knowledge framework is identified as being needed to guide future research on this topic. Until the evidence base becomes more complete, commentators on sustainable diets should not be quick to assume that a dietary strategy to reduce overall environmental impact can be readily defined or recommended. Adv Nutr 2017;8:933–46.

INTRODUCTION

Dietary strategies have traditionally sought to promote health and well-being and to reduce the incidence of diet-related disease. However, in recent years, dietary strategies have increasingly been investigated as an approach to reducing environmental impacts from the food system^{1–3}. The reason for this is that the food system has been recognized as a major source of environmental impact^{4,5}, with a close relation to several of the so-called planetary boundaries⁶. For example, the food system is currently estimated to contribute between 19% and 29% of global greenhouse gas (GHG) emissions⁷ and to account for 70% of global freshwater use⁸. Concerns about the environmental impacts of the food system are compounded by the increasing world population and the shifts to resource-intensive patterns of food consumption that can accompany economic development. Dietary change is not the only way of reducing environmental impacts associated with the food system. Efficiencies in production and reductions in food waste are other important strategies. It has also been suggested that change in the governance of the food system is necessary⁹. Nevertheless, commitment to achieving lower environmental impacts through dietary change appears to be strong, as evidenced by the variety of national food-based dietary guidelines that now incorporate sustainability principles¹⁰.

Life cycle assessment (LCA) is the technique usually used to quantify the environmental impacts associated with the production and consumption of individual products or services, including foods¹¹, and with sufficient data the technique can also be applied to dietary patterns¹². As the name suggests, LCA is distinguished by its life cycle perspective, taking into account the various forms of resource use and emissions to air, soil, and water that occur during the various stages of production, such as in farming, processing, packaging, and distribution. Some studies also include food preparation and waste management. The life cycle perspective is critical because the food system is complex and can involve global supply chains. Through the interconnected nature of modern economies, consumers of food can be linked to environmental impacts far from their local environment. In LCA, complex models are used to evaluate the significance of the various forms of resource use and emissions in relation to environmental issues of concern, known as impact categories. The objective of LCA is to inform decision making to address the processes responsible for the most critical environmental impacts, and to avoid policies and decisions that lead to problem shifting from one life cycle stage to another, from one geography to another, or from one type of environmental burden to another. As such, the international standards that govern the practice of LCA^{13,14} incorporate a principle of comprehensiveness, meaning that there should be consideration given to all relevant environmental impacts.

The research literature that describes and compares the environmental performance of different dietary patterns has expanded greatly in recent years. Already, several reviews of this literature have been published^{15, 16}, with some framed by the broader context of sustainable diets, which can include social and economic aspects¹⁷⁻¹⁹, and others combining environmental performance and nutritional or health indicators²⁰⁻²⁴. The point has been underscored that dietary strategies to reduce environmental impact must be nutritionally complete and support longstanding public health nutrition objectives²⁵. One factor that complicates the interpretation of the current evidence base is the diversity of metrics used to report environmental performance¹⁹. It is often found that metrics calculated by using different methods are reported with the use of the same name. In other cases, the same metric is reported with the use of different names. In addition, there are metrics being used that do not reliably inform about environmental performance and should not be used in the life cycle context. Another factor that complicates the interpretation of the evidence base is that there is often an a priori decision to study one or a particular selection of environmental impact categories and not others. Admittedly, the assessment of the environmental performance of diets is complex due to the many types of food eaten and the diversity of agricultural production methods and local environmental contexts. However, there is danger if conclusions are drawn without critical evaluation of the reliability of metrics and the completeness of impact categories covered. In this context, we performed a literature review of research studies concerning environment and diet with specific attention to impact categories and metrics. The aim was to present the state of the scientific evidence and to identify important knowledge gaps.

METHODS

The use of dietary strategies to reduce environmental impact is a broad and cross-cutting research topic. In the absence of a sufficiently specific clinical research question, it is difficult to apply a formal systematic review method on the basis of a narrowly defined set of keywords and rigid inclusion and exclusion criteria for source identification and selection. The relevant evidence base is also diverse in both quality and experimental design. Randomized controlled trials, which are common in the health care literature, are not typically used in the study of the environmental impact of diets. Few studies concerning environment and diet can be compared without interpretation due to the diversity of modeling choices. As such, an integrative review method was applied to synthesize and critically evaluate the variety of evidence in a structured way^{26, 27}. A narrative review method was not chosen because the scope of the study was beyond a theoretical or conceptual discussion of the topic.

An original search for research articles published in scientific journals was undertaken in February 2017 by using Web of Science (www.webofknowledge.com). The goal was to locate studies that reported an environmental assessment of diets. This is differentiated from the many studies that report environmental assessments of individual foods or food production systems. A wide range of keyword search combinations were used, including: diet*, environment*, LCA, life cycle assessment, footprint*, sustainable, ecological, carbon, GHG, greenhouse gas, global warming, climate, energy use, water, land, nitrogen, phosphor*, nutrient, eutrophication, and pesticide. This search strategy was supplemented by purposive sampling of highly cited review articles with forward and backward searching of citations. The intention was to broadly survey the landscape of journal articles on the topic. Due to the cross-cutting nature of the topic, it is possible that not every relevant article was located.

The Sustainable Development Goals (SDGs), developed by the UN and released in 2015, identify a wide range of issues relevant to sustainable development²⁸. The 17 SDGs, comprising 169 targets, were assessed to identify discrete environmental areas of concern²⁹. Each of the research articles concerning the environmental assessment of diets was then assessed to identify which of the environmental areas of concern found in the SDGs were addressed. The purpose of this analysis was to determine the completeness of coverage of environmental areas of concern by the existing evidence base.

For environmental areas of concern for which a substantial body of literature existed, a critical review of the metrics used was undertaken. Each class of metric was assessed in relation to environmental relevance³⁰ — that is, its reliability to inform about environmental impact in a life cycle context, which, as mentioned in the Introduction, is critical because resource use and emissions occur across the food chain. Where possible, external benchmarks were used in this assessment, such as the international water footprint standard in the case of water-use assessment³¹. For each environmental area of concern, those studies that used reliable metrics were further assessed to identify any generalizable findings with respect to lower environmental impact dietary strategies.

RESULTS

Completeness of coverage of environmental areas of concern

Analysis of the 169 separate targets making up the 17 SDGs showed a wide range of environmental areas of concern (Table 1). The scope of the environmental pillar of sustainable development therefore extends well beyond climate change and the need to mitigate GHG emissions. Also important is the need to address water scarcity (target 6.4), natural resource depletion (targets 8.4 and 12.2), and urban air quality (target 11.6), among others. In total, 14 discrete environmental areas of concern were identified across the SDG targets, expressed by using a variety of terms.

TABLE 1. Alignment of environmental areas of concern identified in the UN SDGs and the research literature concerning lower–environmental impact diets¹

Area of concern	SDG targets	Diet X environment studies, ² %
Water scarcity	6.4	27
Natural resource depletion	8.4, 12.2	12
Urban air quality	11.6	4
Ozone depletion	12.4	4
Human and ecotoxicity	3.9, 6.3, 12.4	7
Climate change	13.1, 13.2, 13.3, 14.3	74
Marine debris	14.1	0
Marine eutrophication	14.1	18
Freshwater ecosystem quality	6.6, 15.1	12
Depletion of fish stocks	14.4, 14.6	1
Deforestation	15.1, 15.2, 15b	41 ³
Land degradation and desertification	2.4, 15.3	
Biodiversity loss	15.4, 15.5, 15.9, 15a	
Invasive species	15.8	0

¹SDG, Sustainable Development Goal.

²Total of 93 studies assessed.

³The diet 3 environment literature generally assesses land use as a proxy indicator for deforestation, land degradation, and biodiversity loss.

The literature search located 93 journal articles that reported on the environmental assessment of diets^{32–124}. Overall, there was a weak alignment of the environmental areas of concern covered by this literature and those identified in the SDGs (Table 1). The most commonly addressed area of concern was climate change (74% of studies). Deforestation, land degradation and desertification, and biodiversity loss are all closely related to land use, which was addressed by 41% of studies. Water scarcity is related to water consumption, which was addressed by 27% of studies. Other environmental areas of concern were addressed by fewer studies. None of the studies addressed marine debris or invasive species. Only one study addressed the depletion of fish stocks, which is immediately relevant to the food system and a major international concern¹²⁵. Only 7% of studies addressed human and ecotoxicity, which relates to the use and management of chemicals and wastes. The use of pesticides and other chemicals in the food systems is an important concern^{126, 127}.

It is well known that GHG emissions are not a proxy for the full range of environmental impacts associated with food production. As discussed by Nemecek et al. (12), agricultural production can affect the environment in important ways that are unrelated to fossil energy use or GHG emissions, including through emissions of nutrients that contribute to eutrophication, the emission of pesticides and heavy metals that are toxic to humans and ecosystems, and depletion of water resources, which leads to water scarcity and affects freshwater

biodiversity. As previously mentioned, the use of land for food production can contribute to deforestation, land degradation, and terrestrial biodiversity loss. Furthermore, although GHG emissions may be of vital importance in some specific food production systems, in the context of the complete food system they may not be the most important environmental area of concern. Castellani et al. (128) undertook an assessment of a basket of 17 food products representative of European Union consumption, and although the results were highly sensitive to modeling choices, <2% of overall environmental impact was attributed to GHG emissions. The highest contribution to overall environmental impact came from human toxicity (cancer and noncancer effects of chemical emissions; >50%). In 2013, the European Food Sustainable Consumption and Production Roundtable released a protocol for the environmental assessment of food and beverage products¹²⁹. This protocol requires 14 different environmental impacts to be assessed, which align broadly with the environmental areas of concern identified in the SDGs. According to this protocol, impact categories can only be excluded from the assessment with justification. Again, this highlights the insufficiency of GHG emissions alone in describing the overall environmental performance of a diet.

Other studies have shown that, in comparing food production systems, the results for different environmental impacts are not necessarily correlated. For example, Ridoutt et al.¹³⁰ showed that, for beef production systems in Australia, the system with the highest carbon footprint had the second-lowest water footprint, and the system with the highest water footprint had the lowest land-use footprint. Comparing various fresh tomato production systems for the Sydney market, Page et al.¹³¹ reported that fruit produced year-round with the use of a high-technology greenhouse system had one of the lowest water footprints but the highest carbon footprint. In summary, considering the 93 located journal articles that reported on the environmental assessment of diets, there was generally an incomplete coverage of relevant environmental areas of concern. Although there was substantial literature found that described GHG emissions and diets, there were many fewer studies that addressed land and water use and their impacts, and fewer studies again that addressed other areas of concern. This imbalance has been noted by other authors as well^{17, 19}. This has important implications for terminology. We have noted a disturbing tendency for sustainable diets to be described as healthy diets with lower GHG emissions (e.g., 38). This is entirely inappropriate. To begin with, sustainability encompasses a wider range of concerns than just the environment, such as social and economic concerns¹⁸. In addition, there are a wide range of concerns relating to the environment, and not just GHG emissions.

Critical review of metrics

Climate change, water use, and land use were the environmental subjects most commonly addressed in the literature (Table 1). For each of these subjects, the metrics used in the literature were classified and assessed in relation to the ability to inform reliably about environmental impact in a life cycle context. Resource use and emissions to the environment can occur at multiple stages along food value chains and in multiple locations. It is important that environmental metrics take into account the different types of resource use, the different types of emissions, as well as any relevant differences in local environmental context in which resource use and emissions occur. When aggregating data along food value chains (agricultural production, processing, transportation, etc.) and across food categories that make up a diet, having common units is necessary but is not the only requirement. Environmental equivalence is also necessary³⁰. For example, it would not be environmentally meaningful to aggregate emissions of different GHGs without first taking into account their relative global warming potential (GWP). Similarly, it would not be environmentally meaningful to aggregate the emissions of different pollutants without taking into account their different fate, exposure, and effect characteristics. A small emission of a highly toxic pollutant could be of greater concern than a larger emission of a relatively benign pollutant. When resource use or emissions are aggregated across the food system and there is not an adequate consideration of environmental equivalence, higher and lower values for the metrics may not be reliably informing about greater and lesser environmental impact.

GHG emissions. GHG emissions, also referred to by the term “carbon footprint,” relate to the climate change area of concern. All of the studies that reported dietary GHG emissions used the GWP metric, which reports results relative to an emission of carbon dioxide (i.e., carbon dioxide equivalent). However, less than half of the studies clearly stated that GWP was assessed over a 100-y time horizon (i.e., GWP100). Because GWP100 is the most widely used GWP metric, it is likely that it was also used in other studies, even when it was not specifically stated. GWP100 is considered to be an environmentally meaningful metric for the assessment of relative climate impact, because it is published by the Intergovernmental Panel on Climate Change¹³² and used in a wide range of industry standards¹³³⁻¹³⁵. However, it is important to note that GWP can be calculated over

other time horizons (e.g., 20 or 500 y) and alternative metrics, such as Global Temperature Change Potential, also exist¹³⁶ and the use of metrics other than GWP100 can affect results when assessing alternative diets. It has also been noted that GWP100 may not be the most informative climate metric in all research and policy contexts¹³⁷.

In only a small minority of studies was the calculation of the GWP metric found to include GHG emissions (and removals) associated with changes in land use and with changes in soil carbon stocks (9% and 3% of studies assessing GHG emissions, respectively). In the case of changes in land use, the explanation is possibly the potential for highly variable estimates for different agricultural products depending on the accounting method chosen¹³⁸. In the case of soil carbon, the explanation is more likely the lack of available data relating changes in soil carbon stocks to specific foods, because changes in soil carbon vary according to local agricultural practices as well as with local soil and climatic conditions. As such, including changes in soil carbon stocks in studies at the level of complete diets is rather difficult. However, the typical omission of soil carbon change in dietary studies can have important implications. The building up of soil carbon stocks is an important GHG mitigation strategy, especially in countries with large land bases. Studies have shown the potential for carbon sequestration in pastures to partially or even completely offset the GHG emissions of ruminant livestock¹³⁹. Studies have also shown the GHG emission benefits of land-use change from annual cropping to pastoral farming¹⁴⁰. Tree planting on farms can also make possible GHG-neutral livestock production¹⁴¹. The key point here is the disconnect between the science that is informing climate action in the agricultural sector and the science that is informing the public health nutrition community about low-GHG-emission diets. On the one hand, the livestock sector is seen as part of a positive strategy to reduce agricultural GHG emissions, whereas on the other hand, reducing the consumption of animal products is often suggested as a key strategy to reduce dietary GHG emissions¹. These 2 perspectives can only be reconciled if the methods used to assess the GHG emissions associated with dietary patterns become more sophisticated and take into account local and regional differences in the agricultural sector and the uptake of sustainable agricultural practices.

Water use. A substantial minority (27%) of the located journal articles addressed water use in some way. Although a variety of terms were found to be used, 4 main types of metrics were identified (Table 2). One of the most commonly used metrics was blue water use, which is the consumption of freshwater from surface-water bodies (e.g., rivers, lakes) and groundwater. The problem with this metric is that it does not differentiate water use in regions of water scarcity from water use in regions of water abundance^{142, 143}. As such, blue water use is not an indicator of contribution to water scarcity, which is the relevant area of concern (Table 1). It makes no sense to aggregate blue water use in a life cycle context because it involves the simple aggregation of water use from locations of differing water scarcity, and as such, the results become uninterpretable. A food item or dietary pattern with a small blue water use in predominantly high-water stress locations could be of greater environmental concern than would a food item or dietary pattern with a larger blue water use in low-water-stress regions. This is the reason why International Organization for Standardization (ISO) 14046:2014 (31), the international water footprint standard, forbids the summation of water use from different locations with different environmental condition indicators.

Green water use is another, less often used, metric to describe water use (Table 2). Green water refers to soil water derived from natural rainfall, which is a precious resource that supports world food production. It has been estimated that between 60% and 70% of global food production is on rain-fed land that relies entirely on green water¹⁴⁴, and over the remaining areas, irrigation is usually supplemental to green water. The importance of careful and wise management of green water must be underscored: for example, through conservation tillage and mulching to avoid unproductive soil water evaporation. In arid and semiarid regions, green water is often the yield-limiting factor. However, green water is only accessible through the occupation of land. The rain that falls on one field does not fall on another. The inseparability of green water and land means that green water use is actually a type of proxy land-use indicator. Unless an agricultural production system changes the amount of precipitation that flows, via drainage, to ground and surface water, the availability of water resources in the region is not affected. As such, the green water use metric is also not compliant with ISO14046:2014 (31) because it does not address the water scarcity area of concern and cannot be used to compare the environmental impact from water use in one location with another, or meaningfully aggregated in the life cycle context.

TABLE 2. Characterization of metrics relating to water use applied in the research literature concerning lower–environmental impact

Metric	Number of studies	Reliability ¹	Description
Blue water use	13	No	Volume of surface and groundwater consumed in the production of the different foods that make up the diet
Green water use	6	No	Volume of soil moisture from natural rainfall consumed in the production of the different foods that make up the diet
Virtual-water footprint	13	No	Sum of blue and green water consumption associated with the production of the different foods that make up the diet; can also include gray water, which is a theoretical volume of water required to dilute the load of pollutants emitted to freshwater to the natural background concentration or a selected water quality standard
Water-scarcity footprint	4	Yes	Each instance of water consumption is multiplied by a local Water Scarcity Index and subsequently summed across the life cycle of the different foods that make up the diet; an International Organization for Standardization (ISO14046:2014)–compliant metric

¹The ability to describe the relative level of environmental impact when applied in a life cycle context.

Another commonly used metric to assess water use is virtual water (Table 2). This is essentially the aggregation of blue and green water use, which effectively compounds the problems identified above and is similarly not compliant with ISO14046:2014³¹. Four studies were found to use a water-scarcity footprint metric. To calculate a water-scarcity footprint, each instance of water use in the life cycle of a food product or a diet is multiplied by the relevant local Water Scarcity Index (WSI). Only after applying the WSI are the local water-scarcity results summed across the life cycle. Several global WSI data sets are available for this purpose, and it is important that results are only compared when the same WSI has been applied¹⁴⁵. Water-scarcity footprints calculated in this way are reliable in quantifying the relative contribution to the problem of water scarcity and are ISO14046:2014 compliant. In summary, a reasonable body of literature exists that describes water use in relation to diets. However, very few studies use a metric that informs about relative level of environmental impact with respect to the area-of-concern water scarcity.

Land use. Slightly more than 40% of the located journal articles addressed land use in some way, with the use of 6 different types of metrics (Table 3). The most common metric used was total land use. The problem with this metric is that it aggregates land use of different types (e.g., pasture, cropping) and of different productivity. It leads to the natural conclusion that foods produced on the most productive land and by the most intensive methods of production are preferable, because these foods (and dietary patterns that include them) will have the least total land use. However, agricultural lands differ in their inherent productive capability due to differing climatic, topographic, and soil properties. Well-managed agricultural lands of lower productivity are not less sustainable than well-managed agricultural lands of higher productivity. In addition, excessive intensification of agricultural land can lead to land degradation and is least supportive of biodiversity, which are 2 of the areas of concern identified by the SDGs. This metric is also inherently biased against pasture and rangeland-based livestock production systems that may utilize large areas, but these areas may be unsuitable for other forms of food production. There is also a bias against agricultural production in developing countries where there may be less access to new agricultural technologies and less adoption of intensive farming practices.

The second, third, and fourth metrics (Table 3) are variants on the total land-use theme. The land use by land-use type, which considers arable and nonarable land separately, is an improvement. However, there is often not a rigid distinction between arable and nonarable land and legume based pastures grown in sequence with crops can offer benefits such as improved soil fertility and a disease break for cereal root pathogens. In addition, the problem of summing together land of different inherent productivity still remains. Other studies have assessed diets relative to a conceptual land-use limit that would enable national food self sufficiency. However, food self-sufficiency is an unrealistic goal for many countries and may not even enhance national food security compared with a more distributed food system. In any case, this metric goes beyond the scope of describing environmental impact. The ecological footprint assesses the use of biologically productive land and water surface required to produce resources and to absorb waste¹⁴⁸. The results are expressed in global hectares, taking into account differences in the productivity of land and water resources. As such, it overcomes one of the major problems associated with other land-use metrics. However, the ecological footprint is much more than a land-use metric because it also incorporates a theoretical quantity of land required to sequester GHG emissions and to provide for energy use. As such, it aims to integrate many types of environmental impacts under a perspective that sees land as the ultimate scarce resource. Interpretation is therefore difficult, and there is no particular relation to the areas of concern: deforestation, land degradation and desertification, or biodiversity loss. The fifth and sixth land-use metrics (Table 3) are distinctly different from the first 4 in that they attempt to address specific environmental areas of concern, rather than the quantum of land use. The soil organic carbon deficit metric is based on soil organic matter as a foundational soil-quality indicator. Loss of soil organic matter is considered to have an environmental impact on soil quality. Generic factors for soil carbon loss under various land uses have been published¹⁴⁶. These generic factors may not accurately reflect changes in soil carbon in specific situations and it is preferable to use local data, although such data may not be readily available for researchers studying diets. The data-intensive nature of the method is its main limitation. Nevertheless, it is considered a reliable metric and has been recommended for use in LCA studies by the European Commission¹⁴⁷. The biodiversity damage potential metric¹⁴⁹ attempts to quantify biodiversity loss by land use. The method is based on differences in species richness between different land-use classes in different biomes. The development of methods to assess land-use impacts on biodiversity in a life cycle context is an active area of research¹⁵⁰, and several new, but related, models have emerged¹⁵¹. These models all have limitations. For example, they do not generally express the positive biodiversity effects of well-managed, seminatural pastures, and they are usually applied in a way that is too coarse to capture positive biodiversity benefits of environmental plantings on farms, or the local differences in biodiversity impact between production systems of varying intensity. Nevertheless, having been developed within the field of LCA, these metrics are considered appropriate for use in a life cycle context, provided their current limitations are taken into consideration. In summary, there are a reasonable number of studies addressing land use and diets. However, as was found for water use, very few use a metric that provides any reliable information about the relative level of environmental impact.

TABLE 3. Characterization of metrics related to land use applied in the research literature concerning lower-environmental impact diets

Metric	Number of studies	Reliability ¹	Description
Total land use	21	No	Total area of arable and nonarable land used in the production of the different foods that make up the diet
Land use x use class	11	No	Land used in the production of the different foods that make up the diet, separately reported for different land-use classes, such as land used for cropping, land used for grazing
Land use relative to a defined limit	2	No	Total land area used in the production of the different foods that make up the diet is compared with a land-availability constraint, such as national agricultural land availability, and reported as a percentage of this limit
Ecological footprint	4	No	A measure of land use required for the production of the different foods that make up the diet, as well as land required for energy production, land for sequestration of emitted greenhouse gases, and water surface area required to support fisheries; the results are expressed in global hectares—globally comparable, standardized hectares with world average productivity
Soil organic carbon deficit	1	Yes	Soil organic carbon content is considered proxy for soil quality; the metric, which is based on generic factors for soil carbon loss for different forms of land occupation ¹⁴⁶ , has been recommended as a default method for use in life cycle assessment studies by the European Commission Joint Research Centre ¹⁴⁷
Biodiversity damage potential	2	Yes	Occupied land areas are classified according to type of use (e.g., annual cropping, pasture) and biome; the biodiversity damage potential is based on differences in species richness between agricultural and natural land

¹The ability to describe the relative level of environmental impact when applied in a life cycle context.

Evidence in relation to diets and environmental impact

Climate change. Climate change is the area of concern for which there is the greatest amount of evidence with regard to diets (Table 1). Study designs can generally be classified into 2 main types. First, there are modeling studies in which the GHG emissions of average diets are quantified and compared to an alternative dietary pattern. Rather predictably, when the intake of foods with a higher GHG emission intensity is reduced or excluded, the total dietary GHG emissions are lowered. However, the alternative dietary patterns that have been modeled to show potential GHG emission savings have not always been nutritionally complete, in that they were developed only on the basis of total energy or on the supply of a single macronutrient such as protein²². This is reflected in the findings of a recent systematic review in which 64% of lower-GHG-emission diets were linked to worse nutritional and health indicators, including higher sugar intake and lower micronutrient intake²⁴. In one study, an average European diet was compared with a modeled diet with a 50% reduction in contents of beef, dairy, pork, poultry, and eggs, which was substituted with a 50% higher intake of bread⁷⁹. Not surprisingly, with a net per capita subtraction of 67.6 kg food from the diet, a substantial reduction in GHG emissions was reported (>35%). However, the value of this type of modeling scenario must be questioned from a nutritional perspective, and also in terms of population acceptance. In another study, the alternative dietary scenarios for Organization for Economic Co-operation and Development countries included replacing either ruminant meat, all meat, or all livestock products with an equivalent quantity of plant protein⁴². The study did not report nutritional indicators and does not appear to have been informed by guidelines for recommended intakes of micronutrients.

More informative are those studies that have modeled the GHG emissions of average diets relative to nutritionally complete recommended diets. In most cases, these studies also reported GHG emission benefits, even $\leq 25\%$ (e.g., 35, 46, 58), although exceptions exist in which GHG emissions are reported to increase [e.g., 6%¹²²]. Largely, this is explained by the typically lower total energy intake of recommended diets than of average diets and the finding that total energy intake and total GHG emissions are positively correlated^{43, 73}. However, these savings in GHG emissions can be counterbalanced by the additional GHG emissions associated with an increased average intake of dairy products required to meet nutrient requirements and dietary guidelines. Larger potential GHG emission reductions have been shown with the modeling of well balanced diets that also limit or exclude high GHG emission-intensive foods. This includes vegetarian and vegan diets (e.g., 40, 51). With the use of linear programming, Wilson et al.⁴⁹ identified a dietary pattern with a reduction of >80% in GHG emissions but with an extreme narrowing of food choice. As diets become more restrictive, increasing care is needed in planning to ensure intake remains nutritionally complete. In Western diets, critical micronutrients typically include vitamins A and B₁₂, zinc, calcium, highly bioavailable iron, and omega-3 fats. Furthermore, the likelihood of a substantial proportion of the population adopting such inflexible dietary patterns, which vary greatly from cultural norms, must be questioned.

The second main study design involves quantifying the GHG emissions of individual diets in a population, followed by the identification of subgroups with desirable nutritional and environmental characteristics (e.g., 45, 53, 73). As expected, actual diets vary greatly in terms of having a combination of both higher or lower-GHG-emissions as well as higher or lower diet quality. Importantly, there is already a wide range of dietary patterns in the community that have the characteristics of lower-GHG-emissions as well as higher nutritional quality. In an Australian study, which was based on >9000 individual adult daily diets, the differences in GHG emissions between the higher quality, lower GHG emission dietary pattern subgroup and the lower quality, higher GHG emission dietary pattern subgroup were 44% for men and 46% for women¹⁵². Critically, the primary differentiating characteristic was the content of energy-dense and nutrient-poor noncore (or discretionary) foods (including alcoholic beverages, sugar-sweetened beverages, confectionary, baked and salted snacks, desserts, and processed meats). Discretionary foods contribute to excess energy intake, they inflate dietary GHG emissions, and they can displace the consumption of nutrient-dense core foods, leading to inadequate micronutrient intake.

In summary, dietary patterns with lower GHG emissions are relatively easy to prescribe. The greater challenge is how to effect dietary change. As far as we are aware there are no statistically valid published studies that describe the nutritional and GHG emission outcomes of a public health nutrition intervention designed to encourage the adoption of lower-GHG-emission diets. Modeling studies, by their nature, make favorable, and usually simplistic, assumptions about dietary substitutions. However, little is known about the way people will actually respond to dietary guidance designed to lower GHG emissions. There is reason to be sober about the prospects for change, given the eating patterns that are prevalent in many countries, despite an abundance of dietary guidance and the very direct personal consequences of unhealthy eating. This is best described as still an emerging area of science with many unanswered questions.

Water scarcity. Compared with climate change, very few of the located journal articles addressed the water-scarcity area of concern with the use of metrics deemed reliable in a life cycle context (Table 4). In relation to the British diet, Hess et al.⁹⁵ compared the water-scarcity footprints of 3 starchy-carbohydrate food choices: a typical serving of locally grown potatoes, dried pasta from Italy, and basmati rice from India. A shift in British dietary preferences toward rice was found to increase overall water-scarcity impacts and displace those impacts from the United Kingdom to India where water scarcity is a greater environmental concern. British potatoes are grown with modest amounts of irrigation (10.8 L/kg) and mostly in regions of relatively low water scarcity. In contrast, the cultivation of basmati rice in India not only consumes more irrigation water (2407 L/kg) but the local regions are generally characterized by moderate to high water scarcity⁹⁵. Hess et al.⁹⁴ also assessed the water-scarcity footprints of the average UK diet and 5 healthier dietary scenarios on the basis of the Eatwell Plate associated with their dietary guide- lines. In all cases, fruit and vegetables made the highest contribution. Overall, the water-scarcity footprints differed little between the diets (<5% change); however, depending on the patterns of trade, major changes in the geographical distribution of the water-scarcity footprints were possible. Notarnicola et al.⁷⁹ studied a basket of 17 foods representative of European Union consumption. Scenarios were also modeled in which 25% or 50% reductions in meat and dairy products were substituted with corresponding 25% or 50% increases in bread. Although these alternative scenarios led to reductions in the water-scarcity footprint, they were not nutritionally complete and did not provide sensible information to inform dietary strategies to reduce environmental impact.

TABLE 4. Summary of evidence in relation to dietary patterns and water-scarcity impacts

Study, year (ref) ¹	Study context	Comparison	Key finding
Hess et al., 2016 ⁹⁵	United Kingdom	Typical portion of fresh potatoes, Italian-produced dried pasta, and Indian-produced basmati rice	The water scarcity footprint of a serving of basmati rice was 2 orders of magnitude greater than a serving of potatoes or pasta
Hess et al., 2015 ⁹⁴	United Kingdom	Average UK diet and 5 healthier diets based on the Eatwell Plate	In all cases, fruit and vegetables made the highest contribution to the water-scarcity footprint; healthier diets led to modest changes in the water-scarcity footprint (-3% to +2%); the potential for large shifts in the geographic location of the water scarcity impacts was noted
Notarnicola et al., 2017 ⁷⁹	European Union	Basket of 17 foods representative of European Union consumption— scenario 1: 25% reduction in beef, dairy, pork, poultry, and eggs substituted with a 25% increase in bread; scenario 2: as above but with 50% reductions or increases	Scenarios 1 and 2 reduced the water-scarcity footprint by 11% and 22%, respectively
Goldstein et al., 2016 ¹²⁴	Denmark	Average Danish adult diet, lacto-ovovegetarian diet, and vegan diet, all normalized to 2000 kcal/d	Compared with the average Danish diet, the vegetarian and vegan diets had 26% and 31% higher water-scarcity footprints, respectively

¹ref, reference.

Finally, Goldstein et al.¹²⁴ compared the average Danish diet with a vegetarian and vegan diet, all normalized to 2000 kcal/d. The vegetarian and vegan diets had 26% and 31% increased water-scarcity footprints, respectively. In summary, the available evidence with regard to dietary patterns and water scarcity is very limited. We identified no generalizable findings. Due to the differences in food systems, trade patterns, and their intersection with regions of high water scarcity, findings may not be transferable from one regional or national context to another.

Land degradation and biodiversity loss. Only 3 of the located journal articles addressed areas of concern related to land use with the use of metrics that are applicable in a life cycle context (Table 5). Even then, these studies used generic impact-assessment models that may not accurately reflect local conditions, as described previously. The study by Notarnicola et al.⁷⁹ that assessed water-scarcity impacts also assessed soil carbon deficit, an indicator of impact on soil health. However, as mentioned in the discussion about water scarcity, the dietary scenarios applied in this study were not nutritionally complete and do not provide sensible information to inform dietary strategies to reduce environmental impact. The studies by Rööös et al.⁴⁷ and Baroni et al.¹¹⁵ assessed biodiversity damage potential. A common finding was that well-balanced diets had lower biodiversity impacts than average diets. Although this finding offers additional support for the adoption of recommended diets, the evidence base is rather limited and could have narrow generalizability due, in particular, to regional differences in livestock production systems. As mentioned, well-managed pasture and rangeland-based livestock production systems can have positive impacts on biodiversity (e.g., 153–155) compared with industrialized livestock production systems that increase demand for cropland and that are more commonly associated with negative biodiversity impacts.

TABLE 5. Summary of evidence in relation to dietary patterns and land-use impacts¹

Study, year (ref)	Study context	Comparison	Key finding
Rööös et al., 2015 ⁴⁷	Sweden	Current Swedish diet, recommended Nordic diet, and LCHF diet, all adjusted to same energy content	Compared with the recommended Nordic diet, the biodiversity impacts were ~ 25% higher for the current diet and ~ 60% higher for the LCHF diet
Baroni et al., 2007 ¹¹⁵	Italy	Average Italian diet and 3 other well-balanced diets: omnivorous (2105 kcal/d), vegetarian (2158 kcal/d), and vegan (2298 kcal/d), produced by using conventional or organic systems	Biodiversity impacts were much higher for the average Italian diet than for any of the 3 well-balanced diets; also, biodiversity impacts were generally higher for diets based on organic farming; biodiversity impacts were lowest for the vegan diet
Notarnicola et al., 2017 ⁷⁹	European Union	Basket of 17 foods representative of European Union consumption— scenario 1: 25% reduction in beef, dairy, pork, poultry, and eggs substituted with a 25% increase in bread; scenario 2: as above but with 50% reductions or increases	Scenarios 1 and 2 reduced the estimated soil carbon loss by ~ 18% and 36%, respectively

¹LCHF, low-carbohydrate, high-fat; ref, reference.

CONCLUSIONS

Although the number of journal articles on the subject of environment and diet has grown enormously in recent years, this remains a relatively new area of research and the evidence base to inform dietary interventions for reduced environmental impact is rather incomplete and scant. Compared with the 14 discrete environmental areas of concern identified in the SDGs, the located journal articles mainly addressed GHG emissions; and although this is undoubtedly an important area of concern, it is not a proxy for the full range of environmental concerns associated with food production and consumption and may not even be the most important one. The located literature also addressed water and land use, but less frequently than GHG emissions, and mainly with the use of metrics that make little sense in a life cycle context and that fail to reliably inform about the level of environmental impact. Some of the environmental areas of concern identified in the SDGs were rarely addressed in the located literature, or not addressed at all. In summary, a reasonable body of evidence exists with regard to diets and GHG emissions, but this cannot be said about the wider topic of diets and environmental impact.

The environmental assessment of diets presents a very complex analytical challenge. Diets are made up of a wide range of individual foods. Some of these foods are minimally processed (e.g., fresh fruit, vegetables, and meats), whereas others are more highly processed and combine various food ingredients. It is not uncommon for larger grocery stores to stock >30,000 individual products. Each of these products has a unique supply chain that reaches back into agriculture, and the individual agricultural production systems can vary greatly, both within and between regions, as can the local environmental context. For example, some agricultural production systems utilize irrigation, whereas others rely entirely on natural rainfall. Where irrigation is practiced, it can be in a region of water scarcity in which environmental flows are compromised or in a region of water abundance in which impacts of water consumption are of little environmental concern.

One of the first challenges in characterizing the environmental impacts of diets is to access data that are accurate in describing the underpinning production systems. However, very often, high-quality data are difficult to obtain and generalizations are made, such as applying a single environmental parameter to an entire agricultural commodity or food category. In other cases, the scope of the assessment is limited. For example, in the case of GHG emissions, changes in soil carbon stocks were rarely considered in the located literature. Furthermore, in the few cases in which changes in soil carbon stocks were considered, generic factors were applied that may not even be indicative of local farming systems. What this leads to is a disconnect between the science that is informing strategic climate action on the ground in the agricultural sector and the science that is seeking to inform the public health nutrition community. This disconnect can only be resolved by improved environmental modeling of diets.

Another challenge is the use of metrics that reliably inform about environmental impact when applied in a life cycle context. In the case of water and land use, we found that appropriate metrics were rarely chosen. Some of the metrics even have the potential to misinform about environmental impact. For example, the total land use metric is inherently biased against pasture and rangeland-based production systems, as well as cropping systems that utilize less intensive production practices or land with lower productive capability. There is no reason to conclude that food production on well-managed land of lower inherent productivity (due to climatic, edaphic, or topographic factors) is less sustainable than food production on well-managed land of higher inherent productivity, simply because the former achieves lower yields and therefore requires greater land use per unit of production.

Taking all of the available evidence, there is little that can be concluded, at this time, about dietary strategies to reduce environmental impact. The limited evidence generally points to recommended diets having lower environmental impacts than average diets, although not in every case. This is broadly explained by the over-consumption of food energy, which is common in most average diets and is also a major driver of obesity. The advantage of this approach is that it is consistent with existing public health nutrition advice and will therefore support improved nutrition, and not only environmental impact reduction. Along the same lines, reducing food waste can also be recommended, although this is not a dietary strategy per se but a common sense, practical action. The importance of strategies to reduce food waste should not be underestimated because it is estimated that 30–50% of all food produced is wasted¹⁵⁶; and in developed countries, the largest proportion of food waste occurs at the household level¹⁵⁷. Modeling studies have also shown the potential for deeper cuts in GHG emissions through the formulation of nutritionally complete diets with minimal inclusion of higher-GHG emission-intensive foods. However, it has yet to be shown, through the use of reliable metrics, how such diets perform with respect to other environmental areas of concern. There are also major

unanswered questions about the effectiveness of interventions to encourage the intake of such diets that offer less flexibility and vary greatly from cultural norms. There is also the potential for unintended nutritional consequences if the food substitutions that occur in practice differ from those that are prescribed. Herein lies a major knowledge gap. It is one thing to develop dietary scenarios to reduce environmental impact, it will be quite another challenge to achieve the successful adoption of such diets.

Perhaps what is most urgently needed is the development of a shared-knowledge framework to inform the design of future research on the topic of environment and diet. At present, the evidence base is not growing nearly as rapidly as the number of new journal articles. The literature is not balanced in terms of environmental areas of concern, there is not enough care taken in the selection of environmentally meaningful metrics, and diets are not always informed by guidelines for recommended intakes of micronutrients. These are just some of the weaknesses of the existing evidence base. A shared-knowledge framework, if developed, would emphasize the need to assess a balance of environmental areas of concern with the use of reliable metrics. The framework would also emphasize the importance of nutritional adequacy, the diversity of dietary patterns already existing within the community, and the existing public health nutrition challenges in achieving recommended intakes of micronutrients (i.e., a whole-diet approach). Furthermore, it would give much greater importance to local variations in food systems, local environmental contexts, and local food-related behaviors. Until such time as the evidence base becomes more complete and robust, commentators on sustainable diets should not be quick to assume that a dietary pattern with a low overall environmental impact can be readily defined or recommended.

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