SUPPLEMENT

Vegetarian Diets: Planetary Health and Its Alignment with Human Health

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ABSTRACT

To maintain planetary health, human activities must limit the use of Earth's resources within finite boundaries and avoid environmental degradation. At present, food systems account for a substantial use of natural resources and contribute considerably to climate change, degradation of land, water use, and other impacts, which in turn threaten human health through food insecurity. Additionally, current dietary patterns, rich in animal products and excessive in calories, are detrimental to both population and planetary health. In order to resolve the diet-environment-health trilemma, population-level dietary changes are essential. Vegetarian diets are reported to be healthy options. Most plant-sourced foods are less resource intense and taxing on the environment than the production of animal-derived foods, particularly meat and dairy from ruminants. This review article explores simultaneously the environmental sustainability of vegetarian diets, and its alignment with people's health. In general, the progression from omnivorous to ovolactovegetarian and vegan diets is associated with increased environmental sustainability. Greenhouse gas emissions resulting from vegan and ovolactovegetarian diets are ∼50% and ∼35% lower, respectively, than most current omnivore diets, and with corresponding reductions in the use of natural resources. Concomitant health benefits could be obtained by shifting from current dietary patterns to sustainable vegetarian diets. Thus, there seems to be an alignment of health and environmental outcomes for vegetarian diets. Although this shows the human health and environmental sustainability benefits of vegetarian diets in high-income countries, questions remain about the challenges in other contexts and the political will to promote meat-free diets as the social norm. *Adv Nutr* 2019;10:S380–S388.

Keywords: ovolactovegetarian, vegan, vegetarian, plant-based diet, sustainable diet, sustainability, environmental impact, environmental nutrition, health, planetary health

Introduction

Interconnection of the food system with planetary and human health

"Planetary health" is the state of the Earth's natural systems or the safe environmental limits within which humanity can flourish. Exceeding planetary boundaries can lead to a state less conducive to human development (i.e., negatively affecting the quality and the sufficiency of food and water) (1). At present, the overall size and economic activity of mankind is exceeding the sustainable capacity of the natural world. According to Rockstrom et al. (2), 3 biophysical thresholds of natural systems have been already crossed: climate change, biodiversity loss, and biogeochemical flows of nitrogen and phosphorous. Soon the planetary limits for global freshwater use, change in land use, and ocean acidification will be reached (2). In turn, climate and environmental changes have affected food production by decreasing agricultural yields and increasing food insecurity in some regions of the world (3, 4). To maintain planetary health, human activities should limit the use of Earth's resources and avoid environmental degradation. With this objective, the Intergovernmental Panel on Climate Change (IPCC) suggested some targeted measures such as reducing the net emissions of greenhouse gases (GHGs) by 45% by 2030, in order to achieve the goal of zero net emissions by 2050 (5).

Among all sectors, the food system accounts for a substantial use of natural resources and is a major contributor to the environmental degradation of planet Earth. It contributes

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20–30% of total anthropogenic GHG emissions, accounts for 70% of all freshwater use, and is a major source of water pollution (6). About 80% of the world's deforestation is related to the food system; and this sytem is the leading cause of changes in land use and biodiversity loss (7). Without corrective measures, the environmental impact of the food system could increase by 50–90% in 30 y, reaching levels that are beyond the planetary boundaries (8).

Although the food system delivers enough food to feed the world's population, the current global dietary patterns result in about half of the world's population being either malnourished, with hunger and micronutrient deficiencies, or eating poorly, resulting in obesity and its associated comorbidities (9–11). All of these conditions contribute to early mortality. Thus, the food system, along with dietary choices, concurrently and unfavorably affect the health of individuals and populations as well as the natural environment. Hence, the use of the term "diet-environment-health trilemma" to draw attention to the quandaries created by these apparently unrelated entities (12).

A growing body of literature is exploring 3 approaches to address these challenges: *1*) improvements in agricultural technology; *2*) reductions in food losses and waste along the supply chain; and 3) shifting food choices and diet patterns of individuals and populations. In recent years, most of the emphasis has been on improving the efficiency of production—to produce more food with less environmental impact. Agricultural and technologic improvements can achieve significant natural resource savings and environmental protection (8). However, this measure alone does not seem to be sufficient, and changes in individual eating habits are also deemed necessary (8).

In wealthy societies, >30% of all the purchased food is wasted (13). Besides the direct gas emissions of the wasted food in the landfills, reducing food waste would result in a reduction in food production and hence corresponding reductions in land, water, and other inputs.

The environmental impacts of population-level food choices are substantial. The type and the amount of food people consume directly affects the type and quantity of food produced. The increased adoption of the Western diet is expected to further damage the environment, and adversely affect the health of the population (14). The potential effect of changes in food choices on environmental sustainability has long been known (15), but has received less research consideration perhaps due to the inherent difficulty of changing food habits. In fact, among the 3 approaches proposed above, changes in food choices and diet patterns of individuals and populations have the potential to contribute the most to the reduction of GHG emissions (8).

Sustainable diets: the role of food choices

In 2010, the FAO indicated that other aspects of the diet, apart from its nutritional value, should be considered, such as its environmental sustainability. A "sustainable diet" is defined as a pattern "with low environmental impact which contributes to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems … nutritionally adequate, safe and healthy; while optimizing natural and human resources" (3).

In general, plant-based dietary patterns are associated with health benefits. Vegetarian diets (meat-free dietary patterns) are associated with reduced risks of many health conditions. Vegetarians have lower incidence of type 2 diabetes, obesity, coronary heart diseases, and other noncommunicable diseases, and greater life expectancy (16–18). The Academy of Nutrition and Dietetics (formerly the American Dietetics Association) has recognized that a well-planned vegetarian diet is healthful and nutritionally adequate, being appropriate for human growth and development. Meat-free diets are suitable not only in the prevention but also in the treatment of many diseases (19–21).

In contrast to the large body of literature assessing the relation between diet and health, there is just a small although emerging body of literature assessing the relation between foods, dietary patterns, and environmental sustainability (22). The environmental impact and use of natural resources in the production of foods differ greatly. Animal-derived foods, particularly meat and dairy from ruminants, are resource intense and more taxing on the environment compared with the production of most plant-based foods (23, 24). **Figure 1** presents the GHG emissions attributed to the production of several foods. As we move up in the trophic chain, the GHG emissions embodied in food production increase several fold. Other environmental impacts also vary widely between plant- and animal-sourced foods. The production of 1 kg of beans requires 3.8 m^2 of land, 2.5 m^3 of water, 39 g of fertilizer, and 2.2 g of pesticide; however, the production of the same amount of beef requires 52 m^2 of land, 20.2 m^3 of water, 360 g of fertilizer, and 17.2 g of pesticide, i.e., ∼8–14 times more resources are needed to produce the beef (24). Differences in the use of resources are observed not only by weight of foods, but also by their protein content. Comparing 1kg of protein from beef and beans, beef protein requires 18, 10, 12, and 10 times more land, water, fertilizers, and pesticides (24). However, individual foods are not consumed in isolation, but in different combinations and proportions within dietary patterns (22, 25, 26). Only recently have studies aimed to assess the effects on the environment of whole diets (27).

The Rockefeller Foundation-Lancet Commission on Planetary Health suggested that dietary changes have the potential to improve both people and planetary health (28). Due to the well-studied connection of vegetarian diets and health, and that plant-derived foods are more environmentally sustainable, meat-free diets have been proposed as an option to replace current prevailing dietary patterns, and thus address the diet-environment-health trilemma.

Therefore, the objective of the current article is to review the latest evidence for the environmental sustainability of vegetarian diets. Furthermore, we advance the present state of knowledge through the assessment of the alignment of

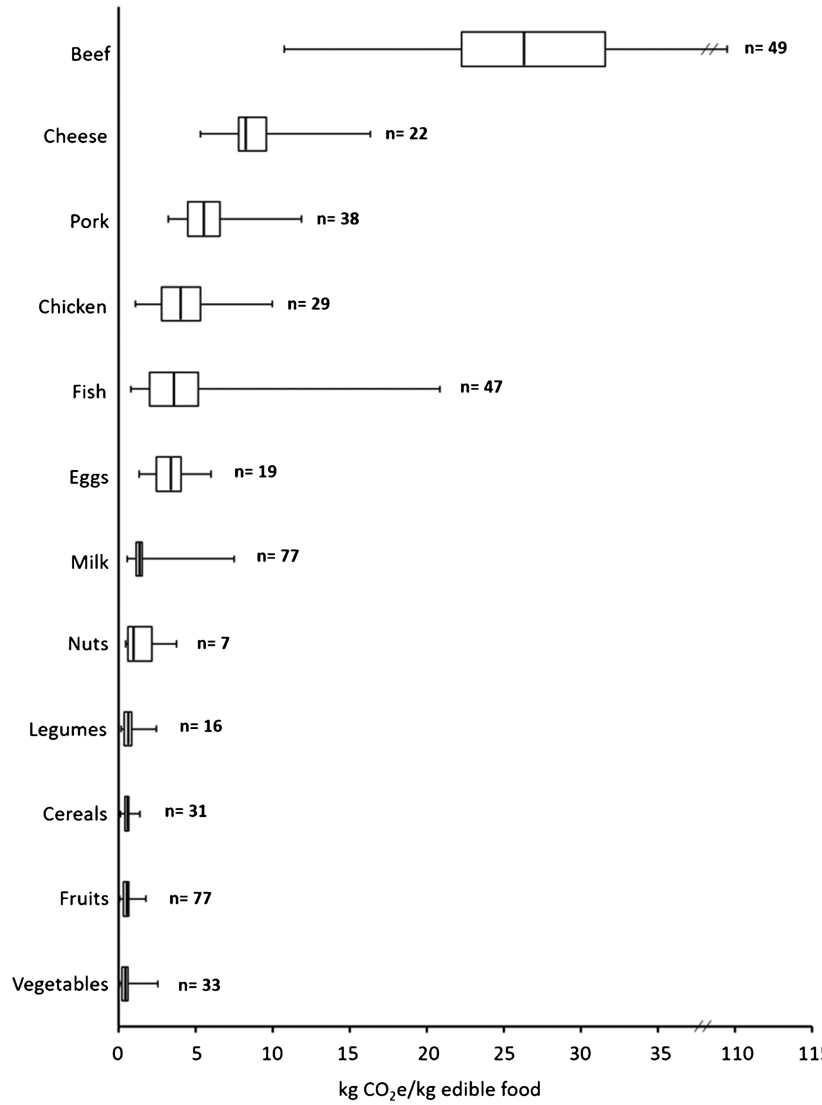

FIGURE 1 GHG emissions in the production of foods. Adapted from Clune et al. 2017 (23). Values represented in the boxplots are minimum and maximum (extremes), IQR (borders of the rectangle) and median (line inside the rectangle). *n* = number of studies included. CO_2e, CO_2 equivalents; GHG, greenhouse gas.

health and environmental outcomes of vegetarian dietary patterns.

Methods

The current study is a review of the literature dedicated to the sustainability of vegetarian diets. Articles included in this review were identified through conventional keyword searching strategies with the use of PubMed, and sustainability-related journals and books. Every effort was made to include all relevant literature published from 2000 to October 2018; however, some articles may have inadvertently been omitted. Our work was exclusively focused on estimating the relative differences of 3 environmental impacts (GHG emissions, land use, and water use) by shifting dietary intake from the currently consumed omnivore diets in high-income countries (taken as the reference diet) towards vegetarian dietary patterns. We also took into consideration as reference diet the projected dietary pattern of a country according to actual consumption tendencies. We did not include in this review any studies where data on the current diet was not reported and thus comparisons with the vegetarian diets were not possible. One or more dietary scenarios could be reported in a study, and each of these scenarios was considered as an independent value when conducting the estimations. Only the articles that reported both people and planetary health outcomes at the same time were taken into consideration when assessing the alignment between these 2 domains. Both theoretic and real vegetarian diet scenarios were included in this review. The theoretic dietary scenarios are those diets that have been designed or modeled with the use of mathematical resolution of some given parameters. Real vegetarian diet scenarios are self-selected vegetarian diets actually consumed by individuals.

We included as vegetarian diets both ovolactovegetarian (meat- and fish-free, but consumption of eggs and dairy products) and vegan (total absence of animal-derived foods). Other dietary patterns—such as flexitarian (vegetarian diet with occasional meat consumption) and pescatarian (lack of meat, but fish consumption)—have been sometimes considered as vegetarian diets but were not included as they are not flesh free.

Results

The environmental sustainability of vegetarian diets

We found 25 studies focused on GHG emissions (12, 29–52), 13 on land use (12, 29, 30, 32–34, 43, 46, 50, 52–55), and 11 on water use (29, 30, 33, 46, 56–62). In total 49, 20, and 15 scenarios have been reported for these 3 environmental impacts, respectively. **Supplemental Table 1** shows the articles considered in the present review, the type of vegetarian diets that were reported in them, and the relative difference in the environmental footprints by shifting from the current diet to the vegetarian diets.

Regarding GHG emissions, 29 ovolactovegetarian and 20 vegan diet scenarios were assessed. The median reductions in GHG emissions by shifting from the current diet to ovolactovegetarian and vegan diets were −35% (range: −13%, −85%) and −49% (range: −23%, −89%), respectively (**Figure 2**). In quantifying the use of natural resources, a similar pattern emerges. Among the 20 scenarios that assessed the land use, the same number referred to ovolactovegetarian as to vegan diets. Compared with the current intake, shifting to ovolactovegetarian and vegan diets would achieve a reduction in the use of land of −42% (range: −27%, −74%) and −49.5% (range: −29%, −80%), respectively (Figure 2). The estimate of water consumed in vegetarian diets has not been so well studied, especially in relation to vegan diets. According to the 11 scenarios which reported information about water savings from shifting to an ovolactovegetarian diet, the median reduction was −28% (range: −7%, −52%); 1 scenario was considered as an outlier as it reported an increment of +85% (46) (Figure 2). Only 4 scenarios reported data related to vegan diets, and the variability among the findings is nontrivial. Although 1 study showed a reduction of 22% compared with the current diet (30), others revealed increments of +1, +33, and +107% (29, 46) (Figure 2).

According to these findings, there is a progression towards environmental sustainability, from omnivorous to ovolactovegetarian and finally vegan diets (with the exception of water use in vegan diets). In fact, this tendency is observed not only in studies based on theoretical dietary scenarios (12, 29, 30, 32–35, 39, 40, 43, 44, 46–48, 53) but also on reports with real vegetarian diets (38, 41). This indicates that results from modeling analyses are consistent with results from observational studies of self-selected diets.

Positioning vegan diets as more environmentally sustainable than ovolactovegetarian diets based on results derived from separate investigations may not be the best approach because of the use of different reference diets and environmental footprint data. However, centering the comparison on the findings of those studies that assessed both types of vegetarian diets, we detected a remarkable consistency in the direction of the reported findings: the fewer animal products consumed, the more sustainable the diet is.

Despite this consistency, it should be noted that any environmental benefits would ultimately depend on the specific foods included in a diet. A recent study advised that it is essential to assess the sustainability of vegetarian diets according to the specific foods actually consumed by the individuals, not by the average nominal diets, because high interindividual variability exists among the diets of vegetarians (30). In fact, not all vegetarian diet scenarios reported in the literature yielded favorable environmental outcomes when compared with the reference diets. For instance, if beef or lamb, foods with a high environmental impact, are replaced by larger quantities of dairy (cheese or butter), the environmental impact gains may be reduced or eliminated (40). Or if meats in the reference diet are replaced isocalorically with vegetables grown in high-energy-demand greenhouses or out-of-season fruits flown from afar, any GHG emissions offsets could be reversed (63). It has also been reported that the water used to obtain calorie-equivalent amounts of nuts, fruits, and vegetables could be higher than several animal-based foods (46, 64). Hence, the diets of some vegetarians could have higher environmental impacts than those of some omnivores.

Five reviews have been previously published on the environmental sustainability of different dietary scenarios, including vegetarian diets, highlighting the relevance of this topic (22, 65–68). Three of the reports, as we did here, were aimed at the environmental savings obtained by shifting the current dietary intake of different countries to different dietary scenarios (22, 65, 67). Although these reviews included vegetarian diets, our review is the only one focused exclusively on meat-free diets. Two of these reviews provide figures of the savings (22, 65) while another is a qualitative study (67). Our results confirm previous findings based on ovolactovegetarian and vegan diets (**Table 1**). As this review includes not only studies collected in earlier revisions, but also recently published articles in the field, it could be considered as an updated version.

Altogether, it could be comfortably concluded that the fewer the animal products included in the diet, the less environmentally degrading a diet is and the fewer resources are required. This fact emphasizes the relevance of reducing animal-sourced foods as a measure to achieve the goal of

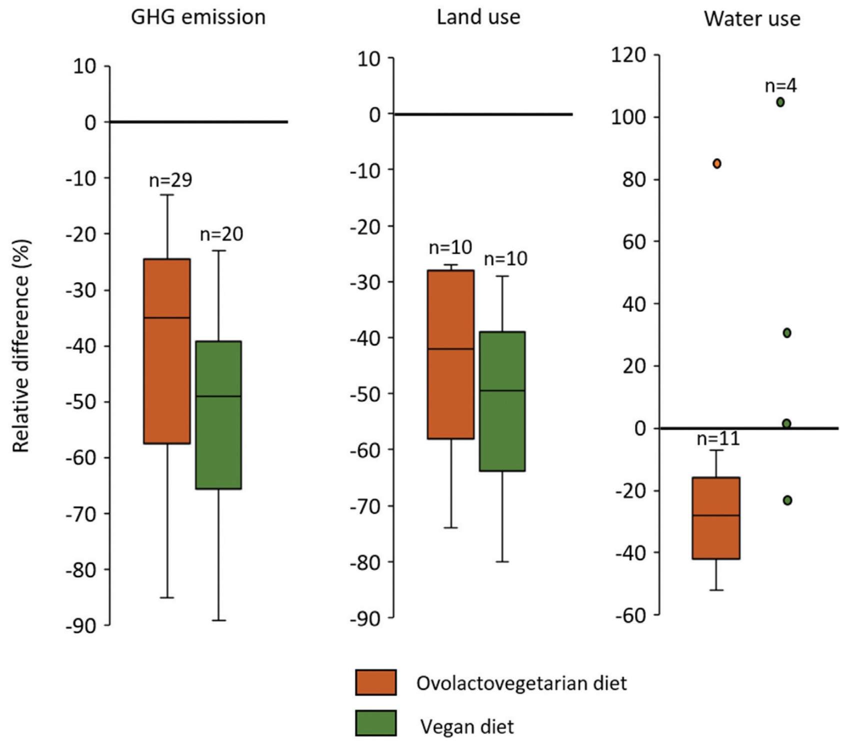

FIGURE 2 Relative difference (percentage) in GHG emission, land use, and water use when shifting from current dietary patterns to vegetarian diets. Black line at 0 on the *x* axis represents current dietary patterns. Values represented in the boxplots are minimum and maximum (extremes), IQR (borders of the rectangle), and median (line inside the rectangle). Dots represent values of specific studies. Orange color represents ovolactovegetarian diets; green color represents vegan diets. Note: on water use, the dot in the ovolactovegetarian diet is an outlier (not included in the calculations of the boxplot). Values on shifting to vegan diets are represented by dots and not in a boxplot due to the small number of published studies. *n* = number of dietary scenarios assessed. GHG, greenhouse gas.

reducing the anthropogenic environmental impact. Shifting from current dietary patterns to vegetarian diets, especially vegan, would be an effective measure to halve GHG emissions, as suggested by IPCC (5). Arguably, it would be more valuable than adopting other suggested plant-based diets that include some meat, such as the Mediterranean diet and those based on national dietary guidelines. The GHG emissions reductions estimated for these dietary patterns were ∼10% (33, 37, 40, 43, 46, 51, 52, 69), considerably less than those obtained by changing to vegetarian diets.

TABLE 1 Relative difference (percentage) in GHG emissions, land use, and water use shifting from current dietary patterns to vegetarian diets[1]

	GHG emissions		Land use		Water use	
	Median (min, max)	*n*	Median (min, max)	*n*	Median (min, max)	*n*
Current review						
Ovolactovegetarian	− 35 (−13, −85)	29	− 42 (−27, −74)	10	− 28 (−7, −52[2])	11
Vegan	− 49 (−23, −89)	20	− 49.5 (−29, −80)	10	+17 (−22, +107)	4
Aleksandrowicz L et al. 2016 (65)						
Ovolactovegetarian	− 31 (−15, −58)	20	− 51 (−28, −67)	7	− 37 (−16, −52[2])	9
Vegan	− 45 (−23, −72)	14	− 55 (−40, −80)	6	+107	1
Hallström E et al. 2015 (22)						
Ovolactovegetarian	− 24 (−18, −32)	7	− 39.5 (−27, −52)	2	—	—
Vegan	− 33 (−23, −53)	6	− 51 (−50, −59)	3	—	—

[1] Elaborated with data from the original studies included in the previous revisions. Computations are ours. *n* = number of dietary scenarios assessed. —, no reported data. GHG, greenhouse gas.
[2] Both revisions detected an outlier (+85%).

Alignment of health and environmental outcomes of vegetarian dietary patterns

According to the existing literature, when compared with currently consumed dietary patterns, vegetarian diets are deemed healthier (16–21) and more ecofriendly (12, 29–62). However, the assessment of the alignment of health and environmental outcomes can only be done from reports that address both parameters at the same time.

Among the studies assessing the environmental impacts of vegetarian diets, only a small number of reports also estimated their health outcome (12, 29, 35, 38, 42, 70). The health and environmental profits studied varied among investigations. Regarding health outcomes, 1 study reported general human health repercussions (70), others addressed all-cause or cause-specific mortality (12, 29, 35, 38, 42), whereas another focused more specifically on the prevention of different diseases, such as type 2 diabetes and cancer (12). In relation to environmental outcomes, the impacts have been evaluated mainly through GHG emissions (12, 29, 35, 38, 42, 70), but also by the use of natural resources, such as land, energy, or water, or combinations of these (29, 70). Nevetheless, some of the individual reports examined the relation between different dietary patterns on health and the environment by assessing their nutritional value instead of their potential health effects (30, 44, 68, 71–75). It is important to remember that the healthfulness of a diet is not necessarily signified only by its nutrient content.

In spite of the variance in health and environmental outcomes assessed by the different reports, global studies have indicated that there would be both less degradation of ecosystems as well as population health benefits if current dietary patterns were replaced with vegetarian diets (12, 29, 35, 38, 42, 70). A general improvement in health and sustainability has been reported for both types of vegetarian diets, i.e., ovolactovegetarian (12, 29, 35, 38, 42, 70) and vegan (29, 35, 38, 70). The reports that assessed and compared the effects on both these types of vegetarian diets indicated that greater health and environmental benefits are derived when current dietary patterns are shifted to a vegan diet compared with an ovolactovegetarian diet (29, 35, 38, 70).

Beyond this remarkable correspondence in the direction of the healthiness and environmental sustainability of adopting vegetarian diets in general, as discussed in the previous section, the sustainability and likewise the healthiness of diets would depend on the specific combination of foods. Vieux et al. (76) showed that unhealthy products such as sugars and salty snacks may have a lower environmental impact per calorie compared with fruits and vegetables, which were associated with higher GHG emissions. This observation suggested that depending on the food groups in the diet, health and environmental dimensions can either match or be discordant.

Three reviews which focused on the human health–environment relation of diets have been recently published (65, 66, 77). Two of them were aimed at the environmental savings and health benefits derived from changing current dietary patterns to different diets, including vegetarian diets (65, 66). Although they both arrived at the same conclusion—namely, that health and environmental benefits could be achieved by adopting vegetarian diets—it should be noted that 1 of them did not distinguish between ovolactovegetarian and vegan diets (66), whereas the other did (65). In that review, the authors also observed that more health benefits and fewer environmental impacts would be achieved by a shift from the current pattern to vegan diets than by a shift to ovolactovegetarian diets (65).

More research is timely as the number of studies reporting simultaneously on the environmental and health outcomes of vegetarian diets is very limited and no strong conclusion can be derived with the current evidence. Nevertheless, all individual studies, as well as previous reviews and the current review, indicate that adopting diets that replace animal-derived food (especially red meat) with plant-based products (i.e., fruits, vegetables, legumes, whole grains, nuts, seeds) provide both planetary and population health benefits.

Gaps in knowledge

The field of sustainable diets and environmental nutrition is still in its infancy. Much more investigation is needed on healthy and sustainable dietary patterns. Until recently, the primary focus has been on GHG emissions, which is considered a good marker of most environmental footprints. These emissions strongly correlate with energy inputs, water use, land use, water eutrophication, nitrogen release, and air acidification (78, 79). However, scientists should assess other environmental factors, such as ozone layer depletion or biodiversity loss, to obtain a more complete understanding of the sustainability of dietary patterns.

Most of the research on diet sustainability has been conducted in high-income countries (80). Are the data similar in low- and middle-income countries? Some data indicate that GHG emissions of foods in low-income countries are lower. In India, investigators found emissions of 0.72, 0.12, and 0.025 kg CO_2 equivalents/kg of fish, rice, and potatoes were emitted, respectively; however, emissions in high-income countries are closer to 3.49, 2.55, and 0.18 kg CO_2 equivalents, respectively, a many-fold increase (23, 81).

The FAO reported that industrialized livestock production is unsustainable (6). However, more research is needed on the sustainability of livestock produced in small-operation family farms where animals are integrated into the functions of the farm and consumed as food at the end of their productive lifecycles. This is of relevance for rural populations in low- and middle-income countries where eliminating meat could adversely affect these population's marginal nutritional status.

In societies where daily meat consumption is the social norm, aspiring to drastically reduce meat consumption is a challenging endeavor. Research is needed to better understand the cultural and socioeconomic factors that influence change in dietary patterns. This represents appreciating determinants, enablers, and barriers in reducing meat consumption or even eliminating it from the diet (82). This research will inform suitable policies for healthy and sustainable eating specific to each society and at the appropriate level, according to the Nuffield intervention ladder (83).

The defining common characteristic of vegetarian diets is the absence of meat. This simple definition does not offer much insight into what foods constitute most vegetarian diets. Depending on the mix and proportion of plant foods—and in some instances, animal-derived foods such as dairy and eggs—the degree of sustainability and healthfulness will vary accordingly. Most analyses on the environmental and health outcomes of vegetarian diets have focused on averaged dietary patterns. Thus, it is possible that those averages hide important differences among specific vegetarian diets according to these 2 issues, as previously highlighted in this paper. Research is needed on the food mix of vegetarian diets to optimize their environmental sustainability and salutary effects.

Conclusions

The aggregate dietary decisions a society makes have a large influence on climate change and other environmental impacts. There is consensus that global transitioning towards a more plant-based diet is essential for maintaining planetary boundaries. Furthermore, vegetarian diets appear to simultaneously offer population and planetary health benefits. In brief, population-level vegetarian patterns have the potential to contribute to the solution of the pressing diet-environment-health trilemma (84). Nevertheless, more research is needed in various contexts to optimize meat-free diets to achieve maximum health and environmental impact benefits. A better understanding of the cultural and socioeconomic contexts will inform effective policy prescriptions.-3

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