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Nutrition and its footprints: Using environmental indicators to assess the nexus between sustainability and food

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Current food systems are associated with the unsustainable use of natural resources; therefore, rethinking current models is urgent and is part of a global agenda to reach sustainable development. Sustainable diets encompass health, society, economy, culture as well as the environment, in addition to considering all the stages that make up the food production chain. This study aimed to perform a review on the importance of using environmental footprints (EnF) as a way of assessing the environmental impacts of food systems. The most used EnF to assess impacts related to the food system was the carbon footprint, followed by the water footprint, and the land use footprint. These EnF usually measured the impacts mainly of the current diet and theoretical diets. Animal-source foods were the ones that most contribute to the environmental impact, with incentives to reduce consumption. However, changing dietary patterns should not be restricted to changing behavior only, but should also involve all stakeholders in the functioning of food systems. We conclude that EnF are excellent tools to evaluate and guide the adoption of more sustainable diets, and can be applied in different contexts of food systems, such as food consumption analysis, menu analysis, food waste, and inclusion of EnF information on food labels.

KEYWORDS

sustainable development, environmental indicators, water footprint, carbon footprint, ecological footprint, food systems

1. Introduction

For a long time, nutrition science has been seen as predominantly biological science, comprehending physiological, biological, genomics, and medical aspects and geared toward the interaction between foods and the human body, aiming at preventing and maintaining the health of individuals and populations (Beauman et al., 2021).

According to the Giessen Declaration, the world where we live today is very different from the world in which the concept of nutrition as science was created. The conventional concept of nutrition as a biological science can be adapted and expanded to also include social and environmental aspects. Hence, nutrition science starts being defined as the study of food systems, foods and drinks, their nutrients and other constituents, and their interactions within and among all relevant biological, social, and environmental systems (Beauman et al., 2021).

Food systems are characterized by a complex relation of elements and activities that involve the production, transformation, distribution, and preparation of foods for consumption. Such food systems are key for the health and nutrition of people, influence environmental wellbeing, and promote social justice [Ericksen, 2008; High Level Panel of Experts on Food Security and Nutrition (HLPE), 2014; Organização Pan-Americana da Saúde, 2017]. In 2014, at the Second International Conference on Nutrition promoted by the World Health Organization (WHO), it was discussed that there is a great challenge of current food systems to promote adequate, safe, diversified, and healthy eating to all due to unsustainable patterns of production and consumption that lead to the scarcity of resources and environmental degradation (Food Agriculture Organization of United Nations World Health Organization, 2015).

The currently prevailing food systems, associated with current ways of life and production, have caused harm to the environment, climate change, and excessive use of natural resources, exceeding the biocapacity of the planet, in addition to direct negative impacts on the economy and society. In face of this scenario, the United Nations (UN) released in 2015 the Sustainable Development Goals (SDG) to be reached by 2030 (United Nations, 2015). Among the 17 goals listed, goals 2, 6, 12, and 13 have a direct relation with sustainable food systems since they seek, respectively, to end hunger, achieve food security and improve nutrition and sustainable agriculture, ensure the availability of water and sanitation for all, promote responsible consumption and production, and foster urgent actions against global climate change.

The production of food for humans and animals is one of the activities that most cause climate change, particularly by using natural resources such as water, soil, and energy. Arable land for agriculture and livestock causes significant emissions of greenhouse gases (GHG), and the use of agricultural pesticides contributes to impoverishing the soil and contaminating rivers and water, in addition to reducing biodiversity (Vermeulen et al., 2012; Aleksandrowicz et al., 2016; Campbell et al., 2017). Rethinking the models of food production and consumption is part of a worldwide agenda that seeks to transform the agroindustry model. Considering the principles of sustainability (environmental, economic, and social), the evaluation of impacts on the environment is one of the ways of incentivizing more sustainable production and consumption.

Environmental indicators are instruments used to assess, compare, and control the impacts on the environment, being a way of keeping a tally of the environmental costs involved in the various steps of processing a product. One example of indicators employed to measure environmental impact at a global scale is environmental footprints, which can be used throughout the food production chain, using the Life Cycle Assessment (LCA) methodology (Garzillo et al., 2019).

The analysis of environmental footprints is also associated with the concept of healthy and sustainable diets. According to the Food and Agriculture Organization of the United Nations (FAO), sustainable diets are dietary patterns that are capable of promoting all dimensions of health and wellbeing of individuals, which have a low environmental impact, and are accessible to all, safe, and culturally acceptable (Food Agriculture Organization of the United World Health Organization, 2019).

Several studies (Vanham and Bidoglio, 2013; Rose et al., 2019; Auclair and Burgos, 2021; da Silva et al., 2021; Vanham et al., 2021) have shown the environmental impacts of diets, from the standpoint of environmental footprints, and also point to the need for changes in dietary patterns and, consequently, food systems, given the impact not only on the environment but also on other dimensions of sustainability.

Furthermore, some dietary guidelines from some countries have already started to discuss the relationship between diets and sustainability. The Dietary Guideline for the Brazilian Population is internationally renowned and is, possibly, one of the first ones to fully incorporate the need for sustainability in the dimension of food supply, expanding the discussion to all three components of sustainability (environmental, economic, and social). Also, the guideline states in one of its five principles that healthy diets derive from environmentally and socially sustainable food systems. Other countries such as Australia, Sweden, Qatar, the Netherlands, Nordic Countries, and some countries of the UK (Brasil Ministério da Saúde, 2014; Monteiro et al., 2015; da Silva Oliveira and Silva-Amparo, 2018; Ahmed et al., 2019) also discuss sustainability in their dietary guidelines. This review is considered essential for the academic community and society as there is still the need to explore content and include factors to assess nutrition from a sustainable perspective. In this sense, this review aims to summarize the applicability of environmental footprints in the context of food consumption analysis and its relationship with nutrition, highlighting the relevance and need for a transformation in the current production model toward more sustainable food systems in a global approach. In this sense, this review seeks to answer the following question: "How is the concept and applicability of environmental footprints inserted in the food system, considering socioeconomic, cultural, environmental, and health dimensions?".

2. Materials and methods

2.1. Search strategy

The information contained in this study comes from an extensive review of the literature on the relationship between environmental footprints and human nutrition. Therefore, this review was carried out in a non-systematic way from February 2021 to December 2021. Google Scholar, PubMed, and ScienceDirect databases were used to identify relevant studies according to the development of the review and complemented with a manual search in the reference lists of selected studies. Books, reports, and official documents were also included. Search terms were the following Health Sciences Descriptors: "environmental footprint," "sustainable diet," and "food consumption." The inclusion criteria were the relevance of the bibliographic material, regardless of the year or place of publication, and articles or documents written in English, Spanish, or Portuguese. Conference abstracts, thesis, preprint, and review articles were excluded. The selection of articles, official documents, books, and reports cover the period from 2000 to 2021. Any disagreement was resolved through discussion between the authors.

2.2. Study selection

Authors reviewed all studies that met the following criteria: (1) Access relation between environmental footprint and food consumption; (2) Available in full-text.

2.3. Data extraction

The following information was extracted from each selected study: Author, year of publication, location, aim, environmental footprints analyzed, food and/or diet data source, and main findings. The methodology used for this study is better described in Figure 1.

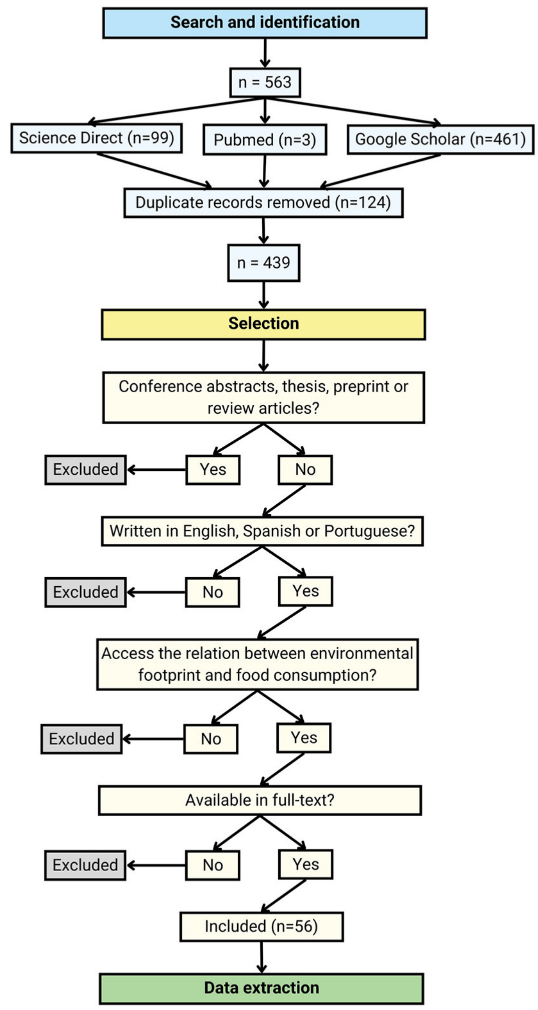

FIGURE 1
Flowchart of study selection process.

3. Background: Concepts, concerns, and advances in the relationship between nutrition and sustainability

Before presenting the results of the study, it is worthwhile to give an overview of how food production and diets have impacted planet earth over the years, as well as introduce the environmental footprints.

3.1. Food systems and environmental impacts

The current food systems have caused several impacts on the environment. Food production contributed to up to 34% of the total GHG emissions in 2015, of which 71% of this amount came from agriculture. Food production is also associated with deforestation, soil degradation, and considerable loss of biodiversity on the planet (Jägerskog and Jønch Clausen, 2012; Vermeulen et al., 2012; Crippa et al., 2021).

Current dietary trends, combined with the forecast of population growth of around 10 billion in 2050, may exacerbate the risks to people and the planet. The effects of food production threaten the stability of the Earth's system *via* emissions of GHG, pollution with nitrogen and phosphorus, loss of biodiversity, and water and land use. Strong trends indicate that food

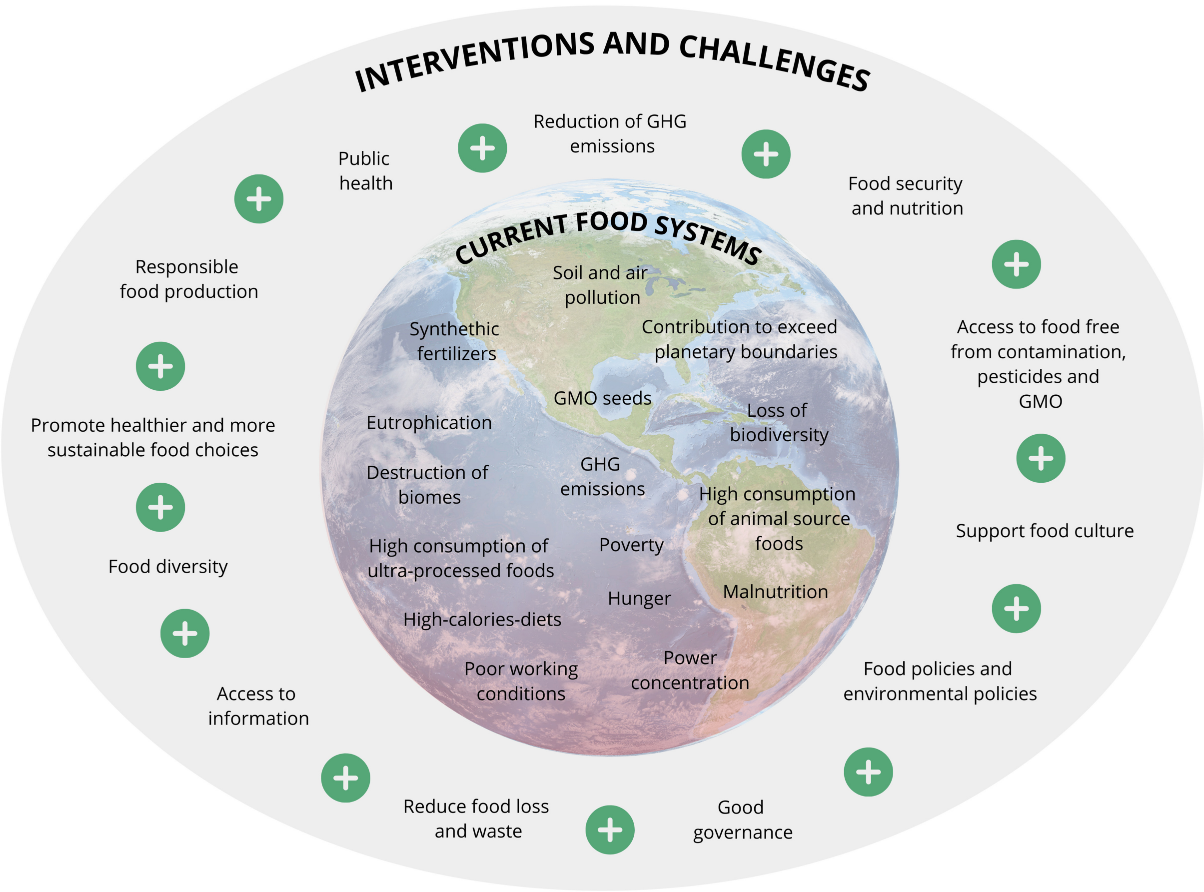

FIGURE 2
Scenario of environmental and health consequences of the food system associated with the planetary boundaries (Campbell et al., 2017; Swinburn et al., 2019; Willett et al., 2019).

production is one of the greatest drivers of environmental change on the planet (Willett et al., 2019).

In 2009, Rockström, along with other scientists, introduced the concept of Planetary Boundaries (PB), which can be defined as the nine processes that regulate the stability and resilience of planet Earth. By identifying those processes, quantitative limits (high risk, increasing risk, and safe) were also proposed within which humanity could develop. Overcoming the limits (safe operating space) would raise the risk of causing changes to the environment, which could be large and irreversible (Rockström et al., 2009a,b).

The nine PB are (1) land-system change; (2) freshwater use; (3) biogeochemical flows—nitrogen and phosphorus cycles; (4) biosphere integrity; (5) climate change; (6) ocean acidification; (7) stratospheric ozone depletion; (8) atmospheric aerosol loading; (9) introduction of novel entities. Steffen et al. (2015) suggest that at least four PBs have been exceeded, which means they are in the uncertainty/risk zone, possibly causing irreparable changes, namely: climate change, land-system change, biogeochemical flows, and biosphere integrity. Recently, studies have indicated that the planetary boundaries of freshwater use (specifically the green water) and novel entities have exceeded (Persson et al., 2022; Wang-Erlandsson et al., 2022).

According to Campbell et al. (2017), the current agricultural production is associated with destabilizing the Earth system and has been identified as the main driver of two PBs: land-system change and freshwater use, besides also directly contributing to climate change. Figure 2 shows a graphical representation of the problems caused by the food system that are also related to the PB and some actions needed to protect the Earth and humankind. It is possible to understand how current food systems impact dimensions that go beyond the environment, such as promoting increased hunger and malnutrition, and changes in dietary patterns, favoring the consumption of foods with a high amount of calories and high consumption of food of animal origin.

In this context, the broad approach to nutrition is increasingly necessary when we approach the issue of current food system impacts. The concept of "sustainable nutrition"

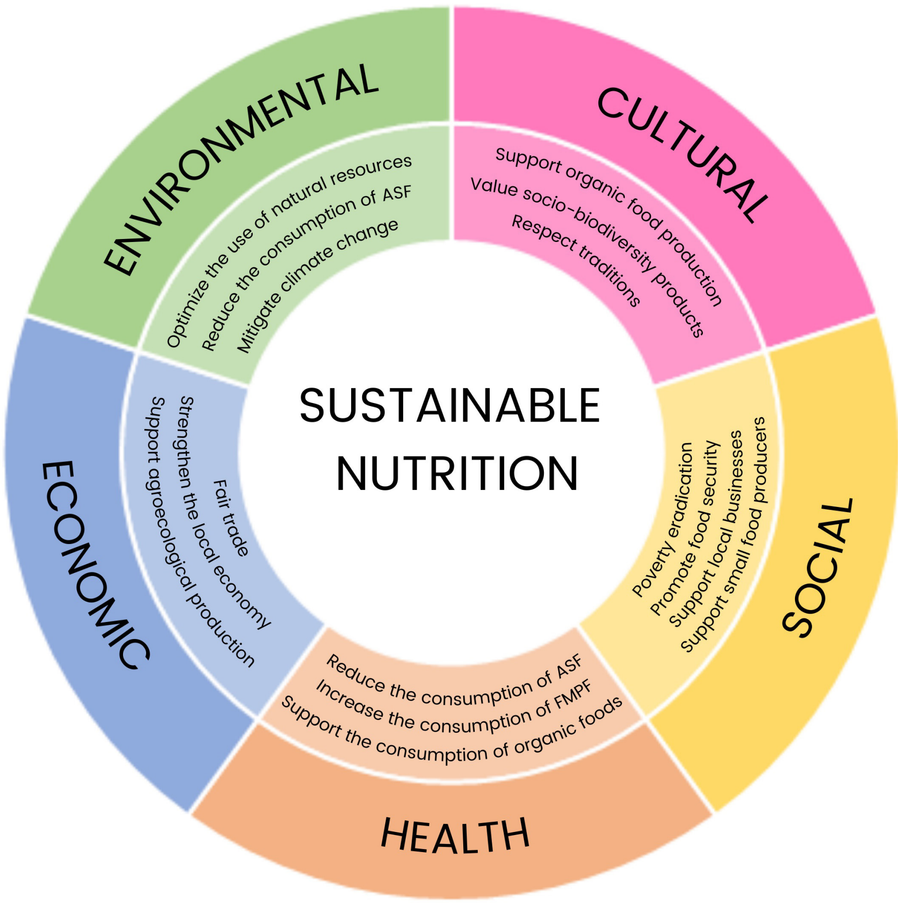

FIGURE 3
Dimensions of Sustainable Nutrition: Symbol of Life. ASF, Animal source foods; FMPF: Fresh or minimally processed foods (von Koerber et al., 2017).

was developed by von Koerber et al. (2017) discusses well how the various dimensions of sustainability should be worked together. Previously, sustainability was defined by three pillars (social, economic, and environmental), the authors, however, include two new pillars to create the concept of "sustainable nutrition" which are health and culture. Health was included since sustainable eating has beneficial effects on health, and culture influences the formation of dietary habits. The authors also enumerated seven principles for individuals to reach sustainable nutrition. Figure 3 illustrates the concept of sustainable nutrition, containing some examples of actions that fit into each of the five dimensions.

This complex relationship between nutrition and food systems was further explored in a recently published report that discusses the Global Syndemic.

The word "syndemic" means a synergy of pandemics, i.e., two or more diseases that coexist and interact and have in common the same social motivators. The Global Syndemic involves obesity, malnutrition, and climate change pandemics (Swinburn et al., 2019).

According to the report, one of the greatest drivers of this worldwide issue is food and agriculture (Swinburn et al., 2019). The planet currently produces enough food to meet the needs of the global population, however, over one-third of the global population is impacted by malnourishment and nutritional deficiencies. It is estimated that one-third of what is produced is lost and wasted, and how the current food systems are organized today influences this dynamic. Because of globalization and the growing need for commodities to attend to the interests of large food corporations, agriculture production tends to favor the production of basic and energetic foods, not focusing so much on nutritional value.

In this context, the current food system delivers low-quality food, with severe expenses in production, distribution, and consumption, and with a high cost to the environment. As a very important factor for sustainability, diets affect different social, cultural, economic, agricultural, environmental, and

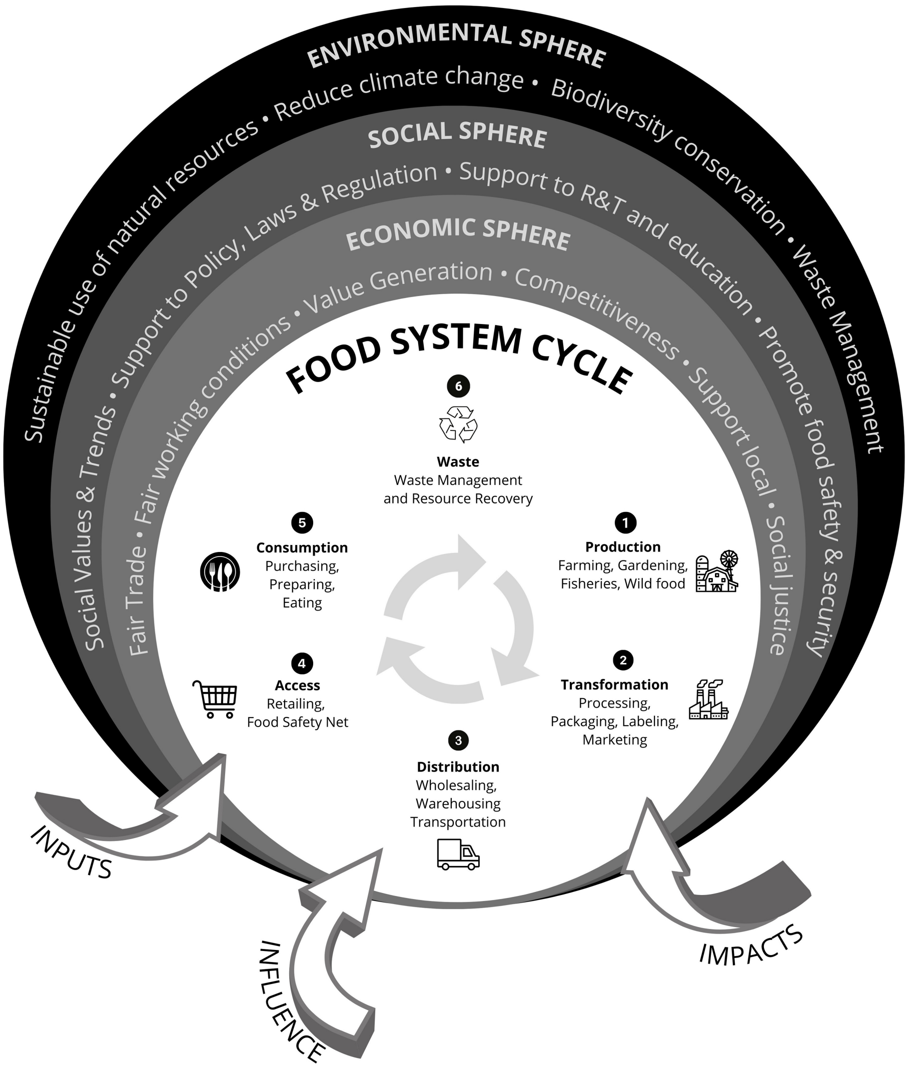

FIGURE 4
Representative scheme of a sustainable food system. R&T, Research & Technology; Inputs, Human Resources (e.g. laborers, managers, professionals) and Natural Resources; Impacts, Outcomes; Influence, Social and Economic Sphere (Harmon and Gerald, 2007; von Koerber et al., 2017; Nguyen, 2018; Bhunnoo and Poppy, 2020).

nutritional factors, which interact with one another (Food Agriculture Organization of the United Nations, 2010). Scientific evidence around the world point to the need to change current food systems toward healthier and more sustainable ones, thinking about the development of more sustainable cities, more resilient healthcare systems, a reduction in food loss and waste, preservation of ecosystems, and reduction in the emission of GHG, among other actions [High Level Panel of Experts on Food Security and Nutrition (HLPE), 2014; Hawkes and Fanzo, 2017; High Level Panel of Experts on Food Security Nutrition HLPE, 2017; IPES-Food, 2017; Food Agriculture Organization of the United World Health Organization, 2019].

In face of this discussion, in Figure 4 we can see a scheme of what a sustainable food system would be like taking into account the three pillars of sustainability and how each one contributes to this system.

3.2. Environmental indicators: Initial concepts

The use of indicators that measure the environmental impact of products, production processes, and behavioral patterns of society has proven important to warn about the damage caused to the environment. Such indicators assess the potential environmental impact of production processes and help identify points where the consumption of natural resources can be reduced or where to introduce technologies that reduce or even eliminate the pollution load. They are objective parameters in the choice of products or the adoption of environmentally favorable practices and, in the context of nutrition, can guide the choices of foods and diets (Garzillo et al., 2019).

Some environmental indicators that may be employed in the analysis of food consumption are environmental footprints. According to van Dooren et al. (2018a), 15 different footprint indicators have been identified, of which ten are relevant to the agricultural and food system. After carrying out a literature review, those authors identified five main footprints that are used as instruments to assess nutrition and diets as a whole. The main footprints are ecological footprint, carbon footprint, water footprint, energy footprint, and land footprint. The carbon and land footprints are derived from the ecological footprint. We will discuss below with greater emphasis the carbon, water, and ecological footprints.

3.2.1. Carbon footprint (CF)

There is not a universally accepted definition for CF, and about which gases are included in this estimative. In this sense, for this review we will accept the concept that the CF is "an estimate of the total amount of GHG emitted from a life cycle perspective from the product under study, thus giving an estimate of the contribution to climate change from the product or service provided" (Röös, 2013). The CF is commonly expressed in carbon equivalent (CO2eq). The emissions for each of the different gases are converted to CO2eq using the global warming potential factor (GWP), considering the GWP for a time horizon of 100 years, as established by the Intergovernmental Panel on Climate Change (IPCC).

The analysis of CF is considered a measure of climate change impact and makes use of the LCA methodology to assess the potential impact on global warming of different activities or individuals.

The LCA methodology began between the 1960s and 1970s, however, only in the 1990s did it become popular worldwide. According to ISO 14044:2006, the LCA can be defined as a "compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle." Normally, the LCA is described in six steps, namely: (1) Raw materials extraction; (2) Material processing; (3) Production, Manufacturing, and Assembly; (4) Distribution; (5) Use; (6) End of life (International Standard Organisation (ISO), 2006; Matthew and Defne, 2012).

It is important to also highlight the need to define the limits of the system under study, i.e., isolate it from the natural system. To analyze the production of grains, vegetables, and fruits, for example, the steps of cultivation and harvest must be analyzed. To analyze ready-to-eat foods, the steps of use, consumption, and preparation of those foods at home must be included. And, finally, an analysis of the entire cycle of food must consider from the beginning until the generation of residues (Pandey and Agrawal, 2014; Röös et al., 2014).

Establishing such boundaries is important so the results can be used in the best way possible, according to the goal. When comparing different agricultural practices, for example, ideally analyses would be used that tally up the emissions up to the gates of the farm. It is also important to point out the difficulties related to the development of such cradle-to-plate studies, for example, since the post-retail steps are controlled by the consumer and those may vary widely, which hinders the calculation (Pandey and Agrawal, 2014; Röös et al., 2014). Figure 5 shows some examples of boundaries that may be used to assess the environmental footprints established for foods.

In that sense, it is common to see a large variation between the values of footprints, even if it is the same product. That variation occurs because, as the analysis takes into account the entire LCA involved in the production of a given food, it may vary depending on the production system (Röös et al., 2014).

3.2.2. Water footprint (WF)

The WF, developed by Arjen Hoekstra in 2002, is an indicator of the use of freshwater, whether directly or indirectly. The WF considers the entire volume of water used throughout the productive chain, also using LCA methodology. The WF is multi-dimensional and works with several concepts, and is subdivided into three: green water, blue water, and gray water. Blue water refers to the use of surface or subterranean water (such as rivers, lakes, and aquifers), green water refers to the use of rainwater, and the gray footprint is associated with pollution, more specifically with the volume of water needed to assimilate the load of pollutants generated (Hoekstra, 2003, 2008, 2011).

Although the water footprint assesses the consumption and pollution of freshwater, it is not a measure that assesses the severity of the environmental impact. That occurs because analyzing the environmental impact caused by those activities also involves analyzing the vulnerability of the local water system and the number of consumers and polluters, therefore, this interpretation will vary according to each water system (Hoekstra, 2003, 2008, 2011).

The evaluation of the WF may have several focuses, i.e., one can assess the WF of processes, products, individuals, a community, companies, a geographically delimited area, or even of humanity as a whole. What will guide this analysis is the objective, from which the calculation of the footprint will be planned, specifying what will and will not be included in the analysis (Hoekstra, 2003, 2008, 2011).

Thinking about food production and consumption, the WF employed would be those with a focus on products and on a consumer or group of consumers. For the WF of a product, the estimate is done based on the amount of water consumed and the pollution generated in all steps of the productive chain. In the case of foods and agricultural products, WF is normally

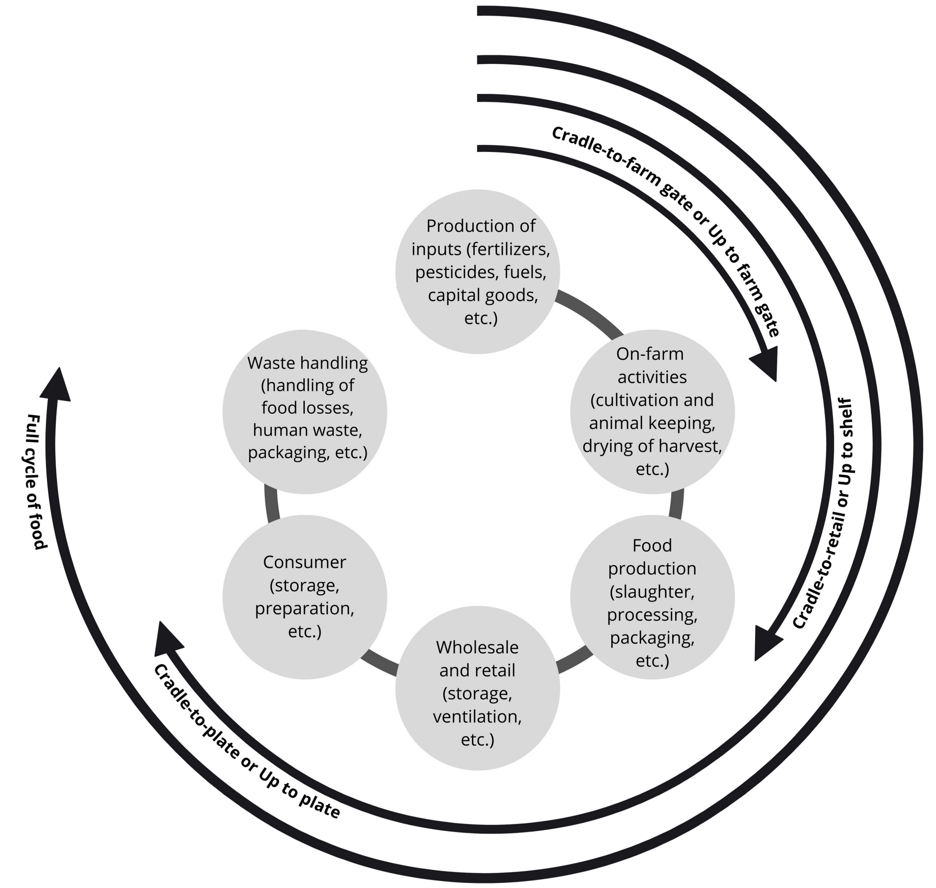

FIGURE 5
System boundaries classifications for food environmental footprint analysis considering the food life cycle (Pandey and Agrawal, 2014; Röös et al., 2014).

expressed as m^3/ton or liters/kg, but it may take other formats. In the case of diet analyses, for example, the values might be expressed in volumes of water/kcal (Hoekstra, 2003, 2008, 2011).

3.2.3. Ecological footprint (EF)

The EF was created as a tool able to assess the demand human activity imposes on the biosphere. More precisely, the EF seeks to measure the biologically productive area of land and water needed to produce all the resources and absorb the residues of an individual, population, or activity. This area analyzed can be defined as biological capacity or biocapacity. Thus, the EF seeks to jointly assess the environmental impacts caused by human beings, impacts that are normally assessed separately, such as GHG emissions (Wackernagel and Rees, 1998; Galli et al., 2012; Garzillo et al., 2019; Global Footprint Network, 2022a).

Biocapacity can be defined as the capacity that ecosystems have of regenerating what people demand from them. The value of biocapacity may change year over year due to human intervention (Global Footprint Network, 2009). In 2017, the biocapacity of the Earth was estimated at 1.6 gha per person, while the global EF was 2.8 gha per person, i.e., a deficit in biocapacity reserve of −1.2 gha per person. In other words, it is estimated that we would need 1.73 planets to sustain the needs of the human population (Global Footprint Network, 2022a).

Biocapacity is measured in five large types of land, whereas the EF is measured in six. The five types of land or areas analyzed by biocapacity are (1) crops; (2) grazing land; (3) fishing grounds; (4) forest; (5) built-up land. For analysis of the EF, the following lands are considered: (1) crops; (2) grazing products; (3) forest products; (4) seafood; (5) built-up land; (6) carbon footprint (Wackernagel et al., 2019).

Both EF and biocapacity are expressed as global hectares (gha). One global hectare is a biologically productive hectare, with the analysis of the mean worldwide productivity. An analysis of gha also takes into account the type of land, seen as each land has different productivity, such as agricultural land being worth more gha than grazing land. In this way, to convert the calculations and reach the value in gha, one needs the equivalent factor. Each territory assessed has its own, which represents the global average productivity for each of the types of land assessed, which is divided by the mean global productivity for all types of land. When we analyze the EF of a product, it has been standardized expressing those results as global hectares per year (Global Footprint Network, 2009; Wackernagel et al., 2019). According to the objective of the study and what it intends to analyze, other approaches may be used and other measures may arise.

The ecological footprint, when compared with the water and carbon ones, is the only one capable of providing an ecological benchmark, i.e., biocapacity, which allows establishing clearer targets. It is also worth pointing out that the water and carbon footprints are closely related to estimates based on the analysis of the life cycle of products or processes, whereas the ecological footprint manages to have a broader approach, that seeks to assess the renewable resources available and their use for consumption by goods and services, not focusing so much on production cycles (Becker et al., 2012). However, EF had been criticized in recent years due to lack of transparency and standardization of analyzes. In that respect, in 2009, the standards for EF analysis were published to ensure that the evaluations of footprint are conducted and communicated more precisely and transparently (Global Footprint Network, 2009).

4. Results and discussion

Dietary patterns can be defined as "the quantities, proportions, variety, or combination of different foods, drinks, and nutrients (when available) in diets, and the frequency with which they are habitually consumed" (Alexandria, 2014). Those patterns are changing due to the increase in movement of people to urban centers and cities, demographic changes, increase in the number of meals had away from home, increase in the size of portions and amount consumed, besides the influence of globalization and commerce on the food sector (Fanzo and Davis, 2019).

Due to these changes, an increase has been noticed in the consumption of critical components and some dietary groups such as red meat, dairy, sugar beverages, and processed and ultra-processed foods, which are rich in sodium, sugar, and saturated and trans fats. These current dietary patterns have a direct impact on health, being considered the greatest risk factors for several forms of malnutrition, deaths, and disability-adjusted life-years (DALYs) around the world (Afshin et al., 2019; Swinburn et al., 2019).

That said, changes in the dietary patterns of populations are increasingly discussed with a view to promoting healthier and more sustainable patterns. According to the FAO, healthy and sustainable diets are "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" (Food Agriculture Organization of the United World Health Organization, 2019). With this in mind, healthier and more sustainable dietary patterns feature lower amounts of animal-source foods, particularly red meat, and processed and ultra-processed products (Swinburn et al., 2019).

The use of environmental indicators such as the WF, CF, and EF may serve as a basis for educational actions and public policies that prioritize the supply of foods that do not negatively impact the environment. According to Lovarelli et al. (2018), one of the greatest environmental impacts caused by activities such as agriculture and food production is related to water consumption. Several studies have also shown the impacts food supply has regarding GHG emissions and other Earth impacts. The consumption of foods at a global level is considered one of the activities that most demand resources, being also considered one of the main drivers of environmental impacts. The food production chain is responsible for 19–29% of all GHG emissions from human activities. Furthermore, 50% of all GHG emissions generated by this food chain come from agricultural activities, related to cattle and emissions of methane gas and nitrous oxide, once again highlighting the impact current dietary patterns have on the environment (Searchinger et al., 2008; Friel et al., 2009; Notarnicola et al., 2017).

According to data provided by the Global Footprint Network, considering the areas analyzed for estimating the EF, the component with the greatest contribution was the carbon footprint with 1.06 gha per person. This same pattern is seen in other countries, which shows the great impact that gas emissions have at both the global and national levels and, as previously mentioned, food production accounts for a considerable percentage of those emissions. The second area that exhibited a greater contribution of EF values was cropland, i.e., the area associated mainly with food production, again showing the impact that food has on the environment and the pressure it exerts on the natural systems of the planet (Global Footprint Network, 2022b).

In face of that context, studies targeting the analysis of the environmental impact of food consumption have been increasingly frequent, especially those associated with the analysis of environmental footprints. For this review, we select articles that analyzed the environmental impacts of food consumption in various dimensions. Figure 6 provides a summary of the selected studies' characteristics.

As seen in Figure 6, most of the selected studies ($n = 49$) used CF as the main indicator to assess the sustainability of food systems. The other footprints that were also widely used were WF ($n = 27$), land use ($n = 14$), energy use ($n = 12$), and EF ($n = 7$). Some studies used innovative footprints such as the studies by Ridoutt et al. (2020, 2021) and Belgacem et al. (2021). The analysis of the different footprints provides a broader view of the different impacts associated with food systems.

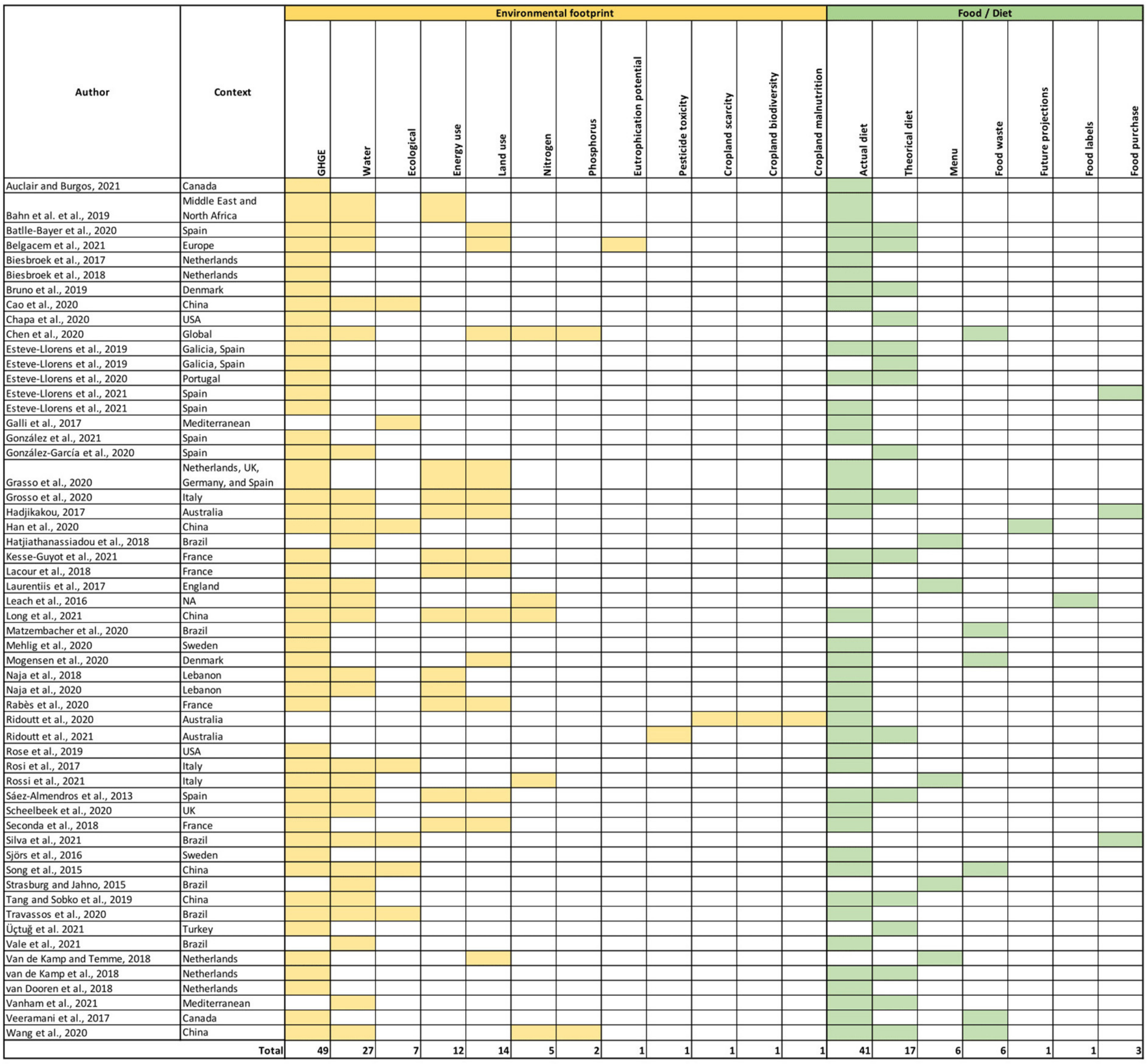

FIGURE 6
Summary of the characteristics of the selected studies ($n = 56$). GHGE, Greenhouse gas emissions.

Ridoutt et al. (2021), for example, highlighted that a dietary shift toward recommended diets could increase the pesticide toxicity footprint compared to the current average diet in the Australian population. This would contradict dietary recommendations to eat a variety of fruits of different types and colors, once those foods make a large contribution to the dietary pesticide toxicity footprint. In this sense, only changing dietary habits is not enough when we are talking about sustainability. In this case, changing how food is being produced, such as reducing pesticide use, is also very important.

Other studies reinforce this discussion about the importance of not only focusing on changing population behavior but also modifying food systems since they are capable of influencing consumer preferences (Sáez-Almendros et al., 2013; Naja et al., 2018, 2020; Esteve-Llorens et al., 2019a,b; Auclair and Burgos, 2021; Belgacem et al., 2021). In this way, the offer of healthier, culturally acceptable, accessible, and sufficient food options, as highlighted in some studies, is in line with what is proposed by FAO (Food Agriculture Organization of the United World Health Organization, 2019).

About the methodologies used by the selected studies to access food, food consumption, and diets, most evaluated current food consumption ($n = 41$). The studies that used the current diet evaluated it directly, but also through the identification of dietary patterns (Veeramani et al., 2017; Naja et al., 2018), and division of the population into groups according to footprint values (Rose et al., 2019; Auclair and Burgos, 2021). A relationship between these values and other information such as sociodemographic factors, food report behaviors, nutrient consumption, and diet quality was also observed (Rose et al., 2019; Auclair and Burgos, 2021).

Another widely used methodology was the theoretical diets ($n = 17$), which in many cases were used in addition to assessing food consumption, scenarios, or standards to compare the environmental impacts. Some theoretical diets used were the Mediterranean diet, the EAT-Lancet reference diet, and different dietary patterns such as vegan and vegetarian (Sáez-Almendros et al., 2013; van de Kamp and Temme, 2018; Bruno et al., 2019; Esteve-Llorens et al., 2019a,b, 2020; Tang and Sobko, 2019; Batlle-Bayer et al., 2020; Grosso et al., 2020; Wang et al., 2020; Belgacem et al., 2021; Ridoutt et al., 2021; Vanham et al., 2021). This analysis is interesting because it allows comparability between different types of dietary patterns and allows us to understand which foods are impacting the most and where it is possible to improve.

In the study by Sáez-Almendros et al. (2013), analyzed the adherence of the Spanish population to the Mediterranean pattern. A greater adherence showed a reduction in all footprints (GHG emissions, agricultural land use, energy consumption, and water consumption), which would also result in a reduction in the consumption of animal-based products and an increase in plant-based products. The authors also point out that in the context of Spain, the adoption of this dietary pattern is in line with the local culture and carries benefits to the health of individuals.

Other methodologies such as menu analysis ($n = 5$), food waste ($n = 6$), and food purchase ($n = 3$) were observed in more than one article. Menu analysis is a different way of assessing food consumption and it is an interesting analysis to be performed, given that more and more people are eating out. The five studies that evaluated menus analyzed school, university, or institutional menus (Strasburg and Jahno, 2015; de Laurentiis et al., 2017; van de Kamp and Temme, 2018; Hatjiathanassiadou et al., 2019; Rossi et al., 2021), and a study evaluated food waste in 6 restaurants with different service categories (Matzembacher et al., 2020). Food waste was a methodology that was often associated with others, as in studies of Song et al. (2015), Veeramani et al. (2017), Mogensen et al. (2020), and Wang et al. (2020) who used food waste along with food consumption analysis, to estimate environmental footprints. However, it can also be used separately (Chen et al., 2020; Matzembacher et al., 2020).

Food Purchase analysis is also a way to access the environmental impacts of food consumption. Three studies (Hadjikakou, 2017; da Silva et al., 2021; Esteve-Llorens et al., 2021a) clearly indicated that they used this information to estimate environmental footprints. In the study by da Silva et al. (2021), the authors highlight the influence of ultra-processed foods on the values of WF, CF, and EF in the diet of Brazilians over the years. The same was observed in the study performed by Hadjikakou (2017), Ridoutt et al. (2020), and van Dooren et al. (2018b). The profile of ultra-processed products directly impacts environmental footprints values, needing to consider the proportion of meat products in the ultra-processed foods (da Silva et al., 2021; Garzillo et al., 2022). We also emphasize that current footprint assessments, which make use of the LCA methodology, often do not consider industrial processes and the wide variety of components that are added to food, as well as the impacts related to the packaging, which are discarded and are sources of environmental impacts. In addition to the environmental impacts, the excessive use of food additives and components present in packaging can also pose a risk to human health. Thus, these foods may be having their environmental impacts underestimated, which may be greater than expected, a doubly negative impact (Seferidi et al., 2020).

Some studies (Song et al., 2015; Batlle-Bayer et al., 2020; Cao et al., 2020; Esteve-Llorens et al., 2020, 2021a; Vanham et al., 2021) used purchase and/or food supply information as a proxy to access the current diet. This is a very interesting way to be applied in different contexts, especially when there are no studies that seek to analyze food consumption more precisely, using instruments such as a food frequency questionnaire and a 24-h dietary recall, for example.

Finally, two other approaches used were food labels and future projections. Leach et al. (2016) worked with food labels, presenting four examples of environmental impact food label designs. According to the authors, information on environmental footprints on labels will enhance a consumer's ability to make informed purchasing decisions based on the environmental impact of products. It is an interesting approach to disseminate information already explored in the literature, making them reach the population. In the study by Han et al. (2020) future projections were made for the CF, WF, and EF of Chinese food systems by 2100. The authors demonstrated that the footprints would peak between 2030 and 2035 and that they would decline by 2100 due to population aging. However, it should be noted that this increase can be modified depending on the public policies adopted.

It is also important to highlight the need to expand studies that assess the impacts of food around the world. As observed in Table 1, most studies are focused on Europe. Five of the six economies contributing the most to total global GHG emissions from the food system are from outside Europe, namely China, Indonesia, the USA, Brazil, and India. India and China are the most populous countries in the world, followed by Indonesia (Roser and Rodés-Guirao, 2019; Crippa et al., 2021).

4.1. The role of animal-source foods in environmental footprint values

A common discussion found among almost all selected studies was the emphasis given to the impacts of animal

TABLE 1 Number of studies per continent.

Continent[a]	Number of studies	%[b]
Asia	12	20
Africa	3	5
Europe	31	53
America	10	17
Oceania	3	5

[a]Two studies were ignored, one due to its global context and the other because it was not possible to identify the context. Two studies were performed in the Mediterranean, which included the African, European and Asian continents. A study was performed considering the African and Asian continents. Therefore, these studies were considered in the count of each continent. [b]This percentage considers only the study included in this table (n = 54) (see Supplementary material).

products, especially red meat (Sáez-Almendros et al., 2013; Song et al., 2015; Strasburg and Jahno, 2015; Leach et al., 2016; Sjörs et al., 2016; Biesbroek et al., 2017, 2018; de Laurentiis et al., 2017; Galli et al., 2017; Hadjikakou, 2017; Rosi et al., 2017; Veeramani et al., 2017; Lacour et al., 2018; Naja et al., 2018, 2020; Seconda et al., 2018; van de Kamp and Temme, 2018; van de Kamp et al., 2018; van Dooren et al., 2018b; Bahn et al., 2019; Bruno et al., 2019; Esteve-Llorens et al., 2019a,b, 2020, 2021a,b; Hatjiathanassiadou et al., 2019; Rose et al., 2019; Tang and Sobko, 2019; Batlle-Bayer et al., 2020; Cao et al., 2020; Chapa et al., 2020; Chen et al., 2020; González-García et al., 2020; Grasso et al., 2020; Han et al., 2020; Matzembacher et al., 2020; Mogensen et al., 2020; Rabès et al., 2020; Ridoutt et al., 2020; Scheelbeek et al., 2020; Travassos et al., 2020; Wang et al., 2020; Auclair and Burgos, 2021; Belgacem et al., 2021; da Silva et al., 2021; González et al., 2021; Kesse-Guyot et al., 2021; Long et al., 2021; Mehlig et al., 2021; Rossi et al., 2021; Üçtug et al., 2021; Vale et al., 2021; Vanham et al., 2021), except for Ridoutt et al. (2021) which presented another view of the problem associated with the analysis of the pesticide toxicity footprint. According to the authors, the fruits had the highest pesticide toxicity footprint scores per serving. Ruminant meats such as beef and lamb had lower pesticide footprint than chicken and pork. In this sense, for this analysis, it is difficult to generalize whether plant-based and animal-based foods are better in terms of environmental impacts. This is an interesting result, since it presents a different point of view of the environmental impacts, highlighting the need to also prioritize how plant-based products are being produced.

Regarding the consumption of animal-source foods, some studies have even pointed out how the reduction in the consumption of these products and the increase in the consumption of plant-derived products are positive not only for reducing the environmental impacts of diets but also at a nutritional and health level (Naja et al., 2018, 2020; Auclair and Burgos, 2021; González et al., 2021), since the association between excessive consumption of meat and the development of obesity, chronic non-communicable diseases (NCDs) such as cardiovascular disease, type 2 diabetes and some types of cancer are already well-known (Micha et al., 2010; Pan et al., 2011; Bouvard et al., 2015; Clonan et al., 2016; Swinburn et al., 2019).

However, this dietary change will not be so simple. It is known that developed countries have a high consumption of red meat, while developing countries, as they develop, increase the consumption of red meat. This is due to the high status associated with meat consumption, Western dietary patterns, and social and cultural factors. It is important to say that eating patterns are relatively conservative and tend to change slowly over the years (Swinburn et al., 2019). In this context, the development of studies that assess the feasibility and acceptability of changing this consumption by individuals is important (van Dooren et al., 2018a; Grasso et al., 2020).

Going beyond individual food choices, we highlight that the involvement of other sectors is essential for changing food systems and achieving sustainability. The change will only be possible through widespread actions at all levels of the food production chain. Actions such as reducing food waste, intensifying and improving food production, encouraging agroecological production, reducing the consumption of animal-source foods, and implementing public policies aimed at producing more sustainable food and protecting the environment are essential (Swinburn et al., 2019; Willett et al., 2019; Jacob, 2021).

Finally, we emphasize that scientific research is a crucial point for the modification of food systems. It is with research that we identify problems, expose evidence and induce change through knowledge (Willett et al., 2019). Environmental footprints play a crucial role since they are very important indicators for accessing the environmental impacts associated with the production and consumption of current foods, being able, for example, to guide better food choices, compare dietary patterns or scenarios to investigate solutions, make projections and investigate the impacts of food waste. The footprints can be used in isolation as well as in combination with other analyzes that access the other dimensions of sustainability, such as social, cultural, and health through the use of information about sociodemographic factors, food behaviors, and association with the development of NCDs. This combined analysis allows the development of studies that manage to cover all dimensions of sustainability, being more assertive and explanatory since food and food systems are influenced by several factors.

We highlight that this review does not intend to do an exhaustive literature review. The main intent was to provide an overview of how environmental footprints have been used in the context of nutrition, sustainability, and food systems. However, this review has some limitations such as a lack of research that use environmental drivers in food studies/food service and food consumption, the variety of data and diversity of studies which makes comparability between studies difficult, the heterogeneous potential of selected studies, with their different biases and scope of the publication.

5. Conclusions

We highlight that footprints have proven to be a great tool to analyze and guide actions toward more sustainable nutrition. It is also worth highlighting that the association of footprint estimation with other analyzes such as diet quality, acceptability, and degree of food processing has further enriched the discussion, by going beyond environmental impacts and embracing other important points in the area of nutrition and public health.

Animal source foods, especially red meat, have been identified as one of the main foods related to climate change. With the analysis of the footprints, the impact that these foods have becomes even clearer. Ultra-processed products are also foods that significantly impact the environment and deserve to be highlighted.

The environmental impact of food production and consumption must reach consumers given that the footprints of food products provide a way for consumers to know about those indicators and how to use them to benefit the health of the planet.

However, it is also important to discuss the responsibility of companies, to internalize the costs, as well as governments, to guide actions in favor of minimizing the environmental, social, economic, cultural, and health impacts that are related to food consumption and the food system. Thinking about the applicability of the footprints, the implementation of environmental labels in food products and meals could be a strategy to promote information to consumers and ways for governmental action to promote policies.

It is important to point out as well that environmental sustainability cannot be split from other dimensions (social and economic) as all dimensions are interconnected. Disseminating this type of information will increase the capacity of all to improve the environmental performance of the food system and the planet.

Author contributions

MH, PR, and LS: conceptualization and writing—review and editing. MH and LS: methodology. MH: investigation and writing—original draft preparation. PR and LS: supervision. All authors have read and agreed to the published version of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1078997/full#supplementary-material

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