Cleaner Environmental Systems 18 (2025) 100289

Contents lists available at ScienceDirect

Cleaner Environmental Systems

journal homepage: www.journals.elsevier.com/cleaner-environmental-systems

Mind the method! A systematic literature review of the methodological choices used to assess the environmental impacts of diets

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ARTICLE INFO

Keywords:
Life cycle assessment
Sustainable diet
Food loss and waste
Dietary data
Transparency
Harmonised methodology
Methodological choices

ABSTRACT

Our food system is a major driver of environmental impacts, and a large proportion of these impacts are due to animal-based foods and food loss and waste. In recent years, many studies have been published looking at the environmental impact of our diets, often in the context of a shift towards a Planetary Health Diet or other environmentally friendly diets. Each study hereby relies on a number of methodological decisions that affect the calculations. We systematically reviewed the methodological decisions made for assessing the environmental performance of diets in literature. We searched the Web of Science database and identified 301 relevant studies published between 1992 and 2022. The aim was to analyse the comparability of methodological approaches, not to evaluate results of individual studies. The review highlights methodological challenges, as many different methodological choices can be made, not all of which can be correct and can often lead to over- or underestimation of the calculated impacts. For example, half of the studies considered only one environmental concern, mostly climate change, and only a third of the assessments considered all life cycle stages. We also found a lack of transparency, particularly when it comes to how food loss and waste are taken into account. Unless we get our methodologies right and aligned, we risk not measuring the right things and masking trade-offs between impacts in impact categories or life cycle stages. We therefore call for greater transparency and a more standardised and holistic assessment of the environmental performance of diets.

1. Introduction

The environmental impacts of the food supply chain - calculated up to the point of sale - currently account for 26 % of global greenhouse gas emissions, 32 % of global terrestrial acidification and 78 % of eutrophication impacts, with the majority of these impacts coming from the agricultural stage (Poore and Nemecek, 2018). In addition, agriculture (including biofuel and textile crop production) is responsible for two-thirds of freshwater withdrawals and uses 43 % of ice-free and desert-free land. Within the EU, when including the use phase and end-of-life impacts, food systems were found to contribute to 38 % of the EU-27 consumption footprint if expressed in tonnes of CO_2 equivalents, or even 49 % if expressed in the single weighted PEF (product environmental footprint) score (European Commission, 2024). Similarly, food is responsible for between 40 and 85 % (depending on the assessment method) of the overall biodiversity impact of EU food consumption (Sanyé-Mengual et al., 2023). A large proportion of the impacts associated with our food system is attributable to animal-based food products (Poore and Nemecek, 2018) and to food loss and waste (FLW) (FAO, 2013; Guo et al., 2023; Poore and Nemecek, 2018). For an average US diet for example, FLW was found to contribute about 28 % of its total carbon footprint (Heller and Keoleian, 2014).

In 2019, the EAT-Lancet Commission proposed the Planetary Health Diet (Willett et al., 2019), which is both healthy and environmentally sustainable and which would, if adopted globally, contribute to staying within the planetary boundaries that define a safe operating space for humanity. The diet calls for a dramatic reduction in the consumption of unhealthy foods such as red meat, and an overall increase in the consumption of pulses, nuts, fruits and vegetables. To transform our diets and food production, the EAT-Lancet Commission proposes, amongst other things, shifting to a more plant-based diet, improving production practices, and at least halving FLW. These strategies are in line with the solutions proposed by other authors (Foley et al., 2011; FSEC, 2024; Springmann et al., 2018; WRI, 2019). Furthermore, the sustainable development goals (more particularly SDG target 12.3) also call for halving FLW (UNGA, 2015). When it comes to shifting to a more plant-based diet, meat and dairy substitutes (MDS) are gaining momentum and market shares are growing rapidly (gfi Europe, 2023; Tziva et al., 2020). With a significantly lower carbon footprint than

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https://doi.org/10.1016/j.cesys.2025.100289
Received 20 March 2025; Received in revised form 12 May 2025; Accepted 30 May 2025
Available online 2 June 2025

Abbreviations

FLW	Food Loss and Waste
DFs	Discretionary Foods
MDS	Meat and Dairy Substitutes
PEF	Product Environmental Footprint

animal-based products (Ritchie, 2022a, 2022b; Smetana et al., 2023), they offer a good solution to reduce the impacts of our diets. However, despite the growing popularity of plant-based products, it seems we are still a long way from a Planetary Health Diet (Loken, 2024). Instead, the composition of our diet has shifted towards higher intakes of animal fats, energy-dense, nutrient-poor foods and highly processed foods (Bodirsky et al., 2020; Clemente-Suárez et al., 2023; Cordova et al., 2023; Mertens et al., 2022; Popkin, 2006). These so-called non-core or discretionary foods (DFs) such as confectionery, cakes, savoury snacks, processed meats and sugar-sweetened soft drinks and alcohol contribute to around 30 % of the food-related emissions of a Swedish or Australian diet (Carlsson-Kanyama et al., 2003; Hadjikakou, 2017; Hendrie et al., 2014, 2016). Furthermore, following the inclusion of coffee and tea into the definition, they contribute to up to 35 % of the biodiversity impact of a typical Swedish diet and to respectively 20 % and 37 % of cropland and consumptive water use (Hallström et al., 2022).

If we want to transform our food system into a system that respects planetary boundaries and assess progress in improving the environmental performance of our diets, we need an appropriate and harmonised set of tools and methodologies to assess dietary impacts. In recent years, many studies have been published looking at the impact of our diets and/or the potential of a shift towards a Planetary Health Diet or other plant-based diets to reduce dietary impacts. Each of these studies is based on a number of methodological choices, such as the kind of dietary data used to formulate the diet, the environmental indicators assessed and the life cycle stages considered in the assessment. In addition, as FLW accounts for about a quarter of our food-related emissions (FAO, 2013; Poore and Nemecek, 2018), the magnitude of the calculated dietary impact is strongly influenced by the decision to include or exclude FLW in the assessment. Finally, given the changes that have occurred in the composition of our diets and the proposal to shift towards a diet with less animal products, it seems only logical that dietary studies also reflect modern foods such as DFs and MDS.

To the authors' knowledge, no clear overview exists on how studies that calculate the environmental performance of diets, have dealt with each of these challenges. We therefore systematically review the methodological approaches applied in peer-reviewed studies that calculate the environmental performance of diets.

Put simply, the environmental performance of a diet is calculated by multiplying the food consumed by the per unit impact of that food. Consequently, this calculation encompasses two distinct disciplines. Firstly, the public health and nutrition discipline is responsible for gathering (and processing) the relevant dietary data, thereby providing insight into the consumption patterns of the population. In order to achieve this, a number of tools can be employed, including food intake surveys and food frequency questionnaires (Bailey, 2021). Alternatively, national food availability data can be utilised to define a diet (Serra-Majem, 2001). The selected tool will determine the level of food information included in the dietary data (Serra-Majem, 2001). In a next step, the environmental impacts of the consumed foods are to be calculated, which brings us to the discipline of environmental sciences. The calculation of environmental impacts associated with foods is typically conducted using a life cycle approach, such as a process-based life cycle assessment, economic input-output life cycle assessment or material flow analysis (Reimann et al., 2010). To calculate the environmental performance of a diet, the two disciplines (public health and nutrition, and environmental sciences) are integrated. Consequently, the methodological choices on which the research is based, will also encompass these two disciplines and will define the results of the assessment. The present review targets researchers from both disciplines and aims at facilitating closer collaboration by identifying and discussing a range of relevant methodological decisions within each of the disciplines.

1.1. Identification of research gap

As several other review studies also examined methodological choices made by scientists, we build on these review studies to identify research gaps. In this way, our paper contributes to an even better insight into the extent to which the approaches taken in literature are appropriate and complete for assessing progress towards an environmentally sustainable diet. Table 1 lists 12 reviews that have looked at methodological approaches used to calculate the environmental performance of diets (Aldaya et al., 2021; Auestad and Fulgoni, 2015; Eme et al., 2019; Frehner et al., 2020; González-García et al., 2018; Hallström et al., 2015; Heller et al., 2013; Jones et al., 2016; Lu and Halog, 2020; Mertens et al., 2017; Reinhardt et al., 2020; Ridoutt et al., 2017). Of these reviews, all but one (González-García et al., 2018) look into the environmental indicators being used in the assessment. Nevertheless, for four reviews this is biased as the inclusion criteria for example say to only include studies that look at greenhouse gas emissions or land use (Eme et al., 2019; Frehner et al., 2020; Hallström et al., 2015; Mertens et al., 2017) and one study sets the additional limitation to only include studies that also look at health impacts (Mertens et al., 2017). The one paper that does not provide for an analysis of used environmental indicators, limits its research to those papers that calculate the carbon footprint of diets (González-García et al., 2018). Out of the 12 reviews, eight look at the life cycle stages considered during the calculations (Auestad and Fulgoni, 2015; Frehner et al., 2020; González-García et al., 2018; Hallström et al., 2015; Heller et al., 2013; Jones et al., 2016; Lu and Halog, 2020; Reinhardt et al., 2020). When it comes to FLW, this topic is never a big focus point of the analysis. In this context, both the underlying dietary data source as well as the system boundaries of the environmental assessment would be important (as will be described later on in Section 2.2). FLW is mentioned in a few review papers in the context of the applied system boundaries (Auestad and Fulgoni, 2015; Lu and Halog, 2020; Reinhardt et al., 2020) or whether or not it is reported as an outcome (Reinhardt et al., 2020). A few other papers (González-García et al., 2018; Hallström et al., 2015) describe how the underlying dietary data sources determine if FLW would be considered, but they do not go into detail on how the reviewed papers then actually deal with this. Two reviews list the underlying data sources that are used (Heller et al., 2013; Mertens et al., 2017), with one (Heller et al., 2013) limiting this exercise to eight out of its 48 reviewed papers. When it comes to modern diets, only one review (Hallström et al., 2015) addresses the need to properly account for processed meat substitutes within the environmental impact calculations to differentiate plant-based scenarios. Furthermore, one paper (Mertens et al., 2017) talks about the discrepancy in the number of food items contained in a nutrition survey and those contained in the environmental impact databases that are used.

In general, the 12 review papers may not be representative of the full body of literature there is on the environmental impacts of diets, as some only cover a very short time span or assessed only a very small number of papers following the set inclusion criteria. Furthermore, considering the rapid pace in which the research field of dietary impacts is evolving, most reviews are published a relatively long time ago with the most recent time span covered ending in February 2021. Finally, some papers set restrictions on the countries or regions they assess, limiting the scope to EU and/or US studies (Frehner et al., 2020; González-García et al., 2018; Reinhardt et al., 2020), resulting in a geographic research gap.

Table 1
Overview of 12 relevant review papers that have analysed methodological approaches for assessing dietary impacts.

First author and year of publication	Review title	Journal	Review period: time span	Number of studies reviewed
Aldaya et al. (2021)	Indicators and Recommendations for Assessing Sustainable Healthy Diets	Foods	2000 – Febr. 2021	368
Auestad and Fulgoni (2015)	What current literature tells us about sustainable diets: emerging research linking dietary patterns, environmental sustainability, and economics	Environment international	unknown - April 2014	31
Eme et al. (2019)	Review of Methodologies for Assessing Sustainable Diets and Potential for Development of Harmonised Indicators	PloS one	1995–2018	51
Frehner et al. (2020)	Methodological choices drive differences in environmentally-friendly dietary solutions	Advances in Nutrition	2014 – Febr. 2019	56
González-García et al. (2018)	Carbon footprint and nutritional quality of different human dietary choices	Global Environmental Change	unkown – Nov. 2017	21
Hallström et al. (2015)	Environmental impact of dietary change: a systematic review	International Journal of Production Research	2005 – Febr. 2014	14
Heller et al. (2013)	Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: a critical review	Sustainable Production and Consumption	1994–2012	48
Jones et al. (2016)	A Systematic Review of the Measurement of Sustainable Diets	Land Use Policy	unknown, max. Up until 2016	113
Lu and Halog (2020)	Towards better life cycle assessment and circular economy: on recent studies on interrelationships among environmental sustainability, food systems and diet	Food Policy	2008–2018	55
Mertens et al. (2017)	Operationalising the health aspects of sustainable diets: a review	The Science of the total environment	2005–Oct. 2015	49
Reinhardt et al. (2020)	Systematic Review of Dietary Patterns and Sustainability in the United States	BMJ open	2015–2019	22
Ridoutt et al. (2017)	Dietary Strategies to Reduce Environmental Impact: A Critical Review of the Evidence Base	The Science of the total environment	unkown – Febr. 2017	93

1.2. Research questions

Based on the analysis of the 12 review papers, we formulated the following research questions to guide our analysis within the present review study. Rather than providing a meta-analysis of the results of individual papers, we focus exclusively on the methodological choices made by researchers when calculating the environmental performance of a diet.

1. What are the chosen underlying dietary data sources? Which environmental concerns are being addressed? Which life cycle stages have contributed to the calculated environmental impacts? Was FLW considered within the calculations? Are studies able to capture modern diets in which MDS as well as DFs are consumed?
2. What might be the flaws of each of the approaches taken? Is there room for improvement?
3. How transparent or clear are authors about the methodological decisions underlying their research?

2. Methods

2.1. Search strategy and selection criteria

A literature search was carried out in November–December 2022 using the Web of Science bibliographic database. Included in the search were peer-reviewed studies that provided for an environmental assessment of diets and dietary patterns, written in English and published between January 1992 and December 2022. No geographical restrictions were set. Papers that assessed single foods, food groups or meals were excluded from the analysis; only those that considered entire diets were retained. In terms of the diets that were assessed, these included both current and modelled diets of an entire country, of a population, or adhering to a specific dietary pattern (such as the vegan or Mediterranean diet). No restrictions were imposed with regard to the methods employed for the collection of dietary data, nor with respect to the methods used for the calculation of the environmental impacts. The full list of search key words as well as the inclusion and exclusion criteria can be found in the Supplementary note 1. The first database search resulted in 4537 records. Through snowballing, an additional 183 papers were identified. All records were screened at title and abstract level. Duplicates were removed, as well as those articles not meeting the eligibility criteria. Next, the full-text of the remaining 428 articles was assessed for eligibility, leading to the further exclusion of 127 full-text articles. Finally, a total of 301 papers was retained in the analysis (Fig. 1).

The review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021). The PRISMA checklists can be found in Supplementary Tables S1 and S2. We did not submit a review protocol to PROSPERO (or similar) as no health-related outcomes are addressed.

2.2. Data extraction, analysis and synthesis of results

The 301 papers were analysed using MAXQDA software (MAXQDA, 2022). The research questions were hereto translated into codes and subcodes, which were then further refined throughout the analysis. The coding focussed on the methods section of each paper; an analysis of the results was out of scope. Next, the codes were further restructured (and merged where necessary) to facilitate the subsequent analysis of the assessment findings (Supplementary note 2). The quantitative analysis of the codes was conducted using Excel, with the frequencies obtained in MAXQDA serving as the basis for this analysis. The code frequencies were hereto transformed into binary codes.

The study starts with an examination of the **general characteristics** of the papers, including the year of publication and the geographical focus of each paper. For the latter, each country that was assessed, was coded in MAXQDA. Subsequently, the countries were classified as low-, middle- and high-income countries in accordance with the World Bank (2023) classification. Papers with a global focus or utilising data from over 100 countries were categorised as "over 100 countries", while those based on data from between 50 and 99 countries were categorised as "between 50 and 99 countries". For those, no income-based categorisation could be done.

Subsequently, we looked at the methodological decisions taken within each paper. An overview of the methodological decisions analysed for the purpose of this review is given in Table 2. First, we determined the **dietary data sources** utilised in the reviewed papers to build or define a diet. To this end, only the main dietary data source on which the paper builds to represent current, future or past diets has been coded. For example, in the event that a paper employs nutrition survey data to assess the current diet, and contrasts this with a recommended diet based on, for instance, dietary guidelines, only the original diet

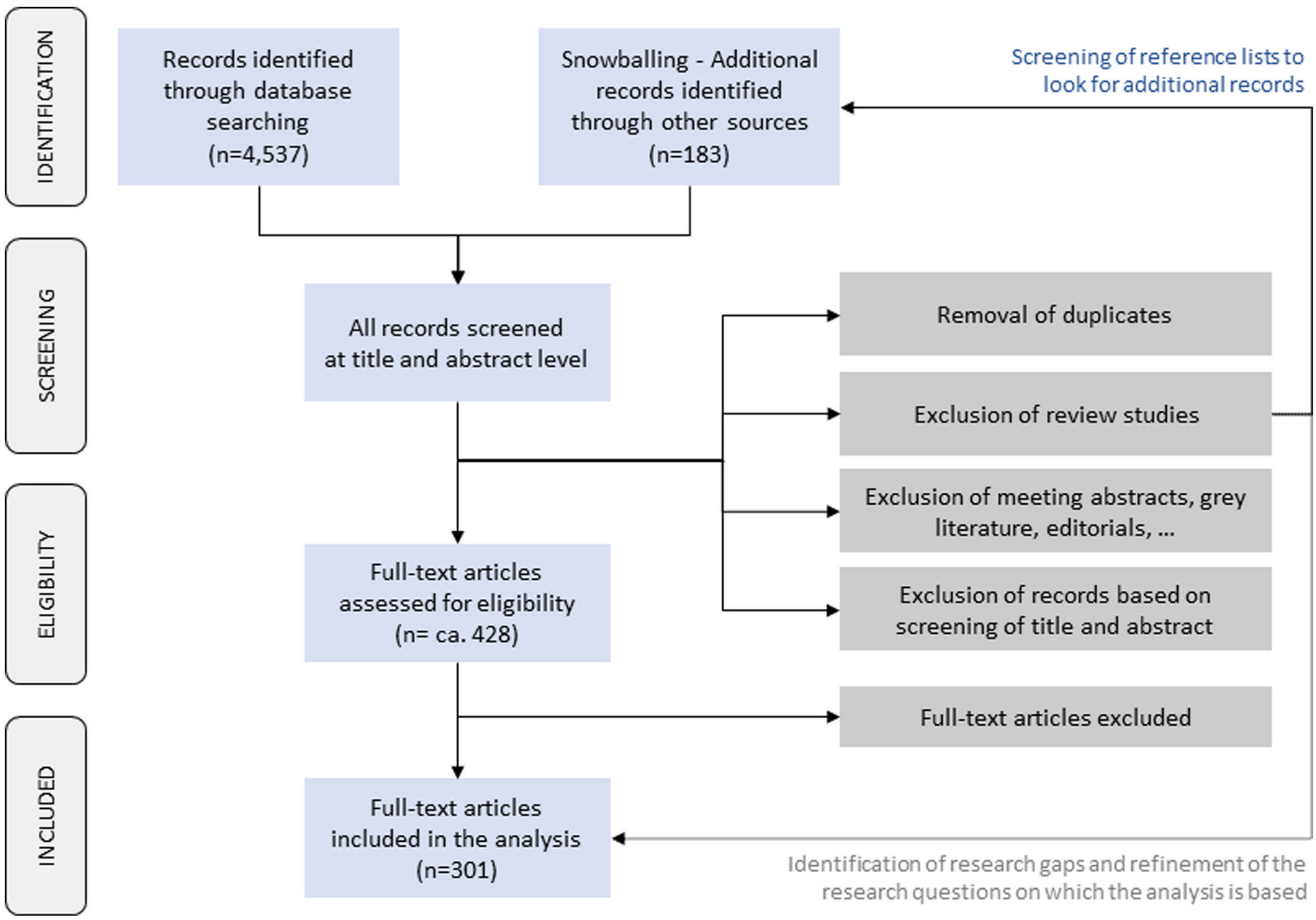

Fig. 1. | PRISMA flowchart illustrating the systematic review **process.** A total of 301 papers, published between 1992 and 2022, were included in the full-text analysis. These 301 papers were written by a total of 217 different first authors. The review studies found during the screening process were used to identify further possibly relevant papers (as part of the snowballing strategy) and to refine the objectives of the present review paper.

based on nutrition survey data was coded. The various dietary data sources were then categorised according to whether they were top-down data at the population level or bottom-up data at the household or at the individual level.

The subsequent stage of the analysis concerns the environmental assessment itself. First, the environmental assessment approach is evaluated in terms of the **environmental indicators** for which impacts are calculated. For each paper, the indicators and environmental areas of concern that were examined were coded. In order to facilitate the analysis, the various indicators were grouped based on the environmental concern they focus on. Table 2 provides for an overview of these environmental concerns; for more information on the individual indicators, we refer to Supplementary note 2.

Second, the **system boundaries** of the assessment were established. These indicate which stages of the food chain are included in the environmental assessment: agricultural stage, processing, distribution/supply chain transport, retail or point of sale, consumer stage and waste management. Multiple system boundaries may be applied within a single paper, for instance when more than one environmental indicator is being assessed with differing system boundaries for each indicator. It should further be noted that multiple indicators within a single paper for which the same system boundary was used, are not being counted on more than one occasion. The analysis therefore only demonstrates the number of distinct system boundaries employed within each paper, regardless of the number of times each specific system boundary was utilised within that paper.

In instances where further information was required, additional sources were consulted, for example, if a paper stated that the assessment was conducted in accordance with the approach outlined in Publication X. Moreover, in instances where an environmental database or dataset was referenced, supplementary sources were consulted to ascertain whether the employed system boundaries were documented in a manual or methods description.

The third step involves an investigation into the manner in which **food loss and waste** (FLW) is considered. This may be achieved in two ways. One potential approach is to incorporate the quantities of food that end up as FLW in the dietary data that forms the basis for the diet in question. Consequently, the extent of each dietary data source is evaluated. Does the dietary data exclusively encompass food items that are actually eaten, or does it also encompass food items that are purchased but not consumed (and subsequently wasted), and/or food items that are produced but never reach the consumer due to loss along the supply chain? The extent to which these additional food quantities are included will have an impact on the outcome of the environmental assessment of a diet or dietary pattern. As an alternative approach, authors may include the quantities of food that end up as FLW in environmental impact calculations by assuming that a larger amount of food must be introduced upstream into the food chain to account for FLW. This approach requires the consideration of the relevant life cycle impacts associated with the additional food quantity. To illustrate, in order to assess the impacts of purchasing 1 kg of apples, it is necessary to assume that 1.067 kg of apples must leave the farm gate and enter the food chain

Table 2
Methodological decisions under study in this review paper. Each of these decisions was duly coded (using MAXQDA) in the 301 reviewed papers and subsequently analysed.

Methodological decision	Description
Dietary data sources used to build or define a diet	Categorisation of dietary data sources into: - Individual level data or food intake data, such as nutrition surveys, food diaries or modelled individual diets - Household level data such as food expenditure surveys or statistics - Population level data such as food availability data
Environmental concerns addressed in the environmental assessment	Categorisation of studied indicators into the following concerns: - Climate - Land - Biodiversity - Water - Energy - Resource use, minerals/metals - Nitrogen & Phosphorous flows - Acidification - Chemicals & toxicity - Air quality - Ionising radiation - Ecological footprint - Other
Life cycle stages included in the system boundaries of the environmental assessment	Categorisation of the assessments into: - Cradle-to-farm - Cradle-to-processing - Cradle-to-retail/point of sale - Cradle-to-consumer (focus on consumer transport and/or consumer storage and preparation) - Cradle-to-grave - System boundaries not clear
Accounting for food loss and waste (FLW)	Categorisation of the (adjusted) dietary data into data that: - Includes FLW - Excludes FLW - Unclear Categorisation of the environmental impact calculations into: - Considers FLW - Does not consider FLW - Unclear
Granularity of data: focus on modern diets	Focus on both the dietary data collection process and the environmental impact data that are used: are they able to capture the consumption of meat/dairy substitutes (MDS) and discretionary foods (DFs)?

in order to account for all post-harvest losses along the supply chain, thus enabling the consumer to purchase 1 kg of apples (Goossens et al., 2018). It should be noted that, for the purpose of this paper, we did not investigate how each of the papers deals with for example the management of FLW; instead, we focus on how quantities of food that end up as FLW are being considered. For other FLW matters, we refer to review papers such as the ones from Omolayo et al. (2021) or Bernstad Saraiva Schott and Cánovas (2015).

The level of aggregation and detail of both the dietary data source on which the diet is based, as well as the environmental impact data to which the dietary data are linked will determine which foods are included in the assessment. In a next step, we therefore assess **the granularity of the data** that was used, both during the data collection process as well as in the secondary data (environmental databases or literature sources) that are used. We hereby focus on the suitability of the approaches employed in the reviewed papers for assessing **modern diets that include meat/dairy substitutes and discretionary foods.** In order to achieve this, we examine readily available information on both the dietary data collection process and the secondary data (such as environmental databases) that are used. It was out of scope to analyse in detail each of these secondary data sources. However, a few exemplary analyses were performed to provide for a general impression.

A theoretical analysis is conducted to examine the **shortcomings of the methodologies employed** and to assess the impact of the methodological decisions on the calculated dietary impacts. Moreover, recommendations are provided regarding the preferred methodological decisions. Finally, an assessment is made of the **transparency** of the authors with regard to the methodological decisions underlying their research.

In the event that no (definitive) information could be obtained regarding a specific characteristic, it was coded as “missing”. The potential for bias due to missing results was considered during the analysis. Results were analysed quantitatively if the share of missing results was below 5 % (based on Kraus and Schmidt (2022)). However, when the number of missing results exceeded this threshold, it was determined that the methodology employed in the reviewed papers was inadequately documented, precluding the possibility of a quantitative analysis. This limitation was observed in the consideration of FLW during the environmental impact calculations, and in the consideration of modern foods such as discretionary foods and meat or dairy substitutes.

3. Results

The initial search for papers investigating the environmental impact of diets yielded 4720 studies, of which 301 met our inclusion criteria (Fig. 1). Furthermore, during the screening process, we found 12 review papers that looked at methodologies underlying the calculations.

3.1. Descriptive characteristics of the 301 reviewed papers

Fig. 2 illustrates how the number of papers that look into the environmental performance of diets increased sharply in recent years. From this chart, it is clear that 48 % of the papers included in the review were published in the last three years (2020–2022). All studies can be found in Supplementary Tables S4 and S8.

Of the 301 papers, 18 provided a global assessment and/or covered more than 100 countries while two papers considered 50–99 countries simultaneously and three papers did not mention any countries. The majority of papers (n = 278) used data from one or up to 50 countries. As shown in Fig. 3 (and Supplementary Fig. S1), a potential for geographic or income bias was found in these papers: 81 % of the countries that were assessed refer to high-income countries, whereas middle-income and low-income countries were looked at in only 6 % and 1 % resp. of the cases. Furthermore, 70 % of the quoted countries is located in Europe and Central Asia. This potential for geographic or income bias has also been highlighted in other reviews (Aldaya et al., 2021; Eme et al., 2019; Fresán and Sabaté, 2019; Jones et al., 2016).

3.2. Methodological decisions underlying the calculations in the 301 papers

The following sections summarise the results of the analysis; an overview of the detailed characteristics of each study is given in Supplementary Table S8.

3.2.1. Dietary data sources used to formulate a diet

A wide range of data can be used to formulate a diet; for a detailed categorisation and description of the various types of dietary data sources found in the reviewed papers, we refer to Supplementary Table S6. While for most papers a single main data source was identified; two data sources were used concurrently as main data source in five papers. More than half of the papers (56 %) used data collected at the individual level, mostly nutrition surveys, as the basis for their

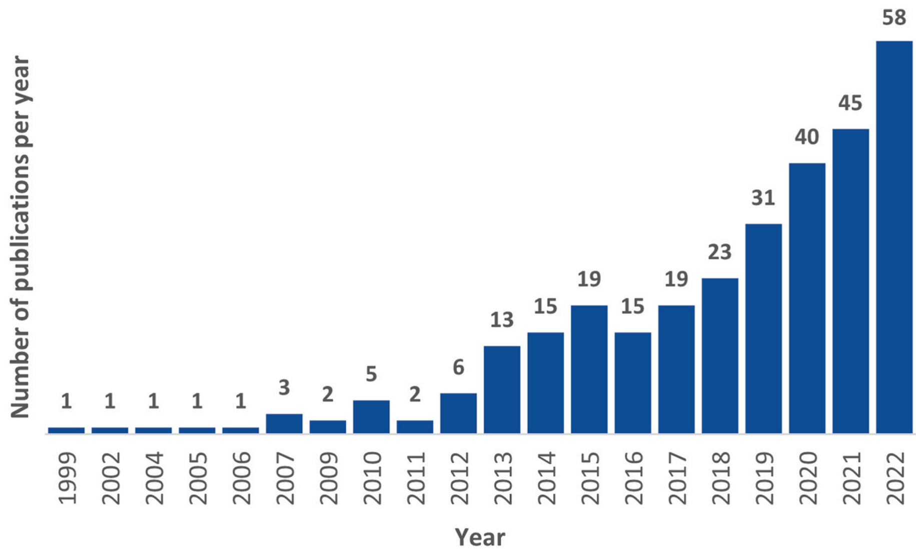

Fig. 2. Number of papers published per year for the period 1992–2022.

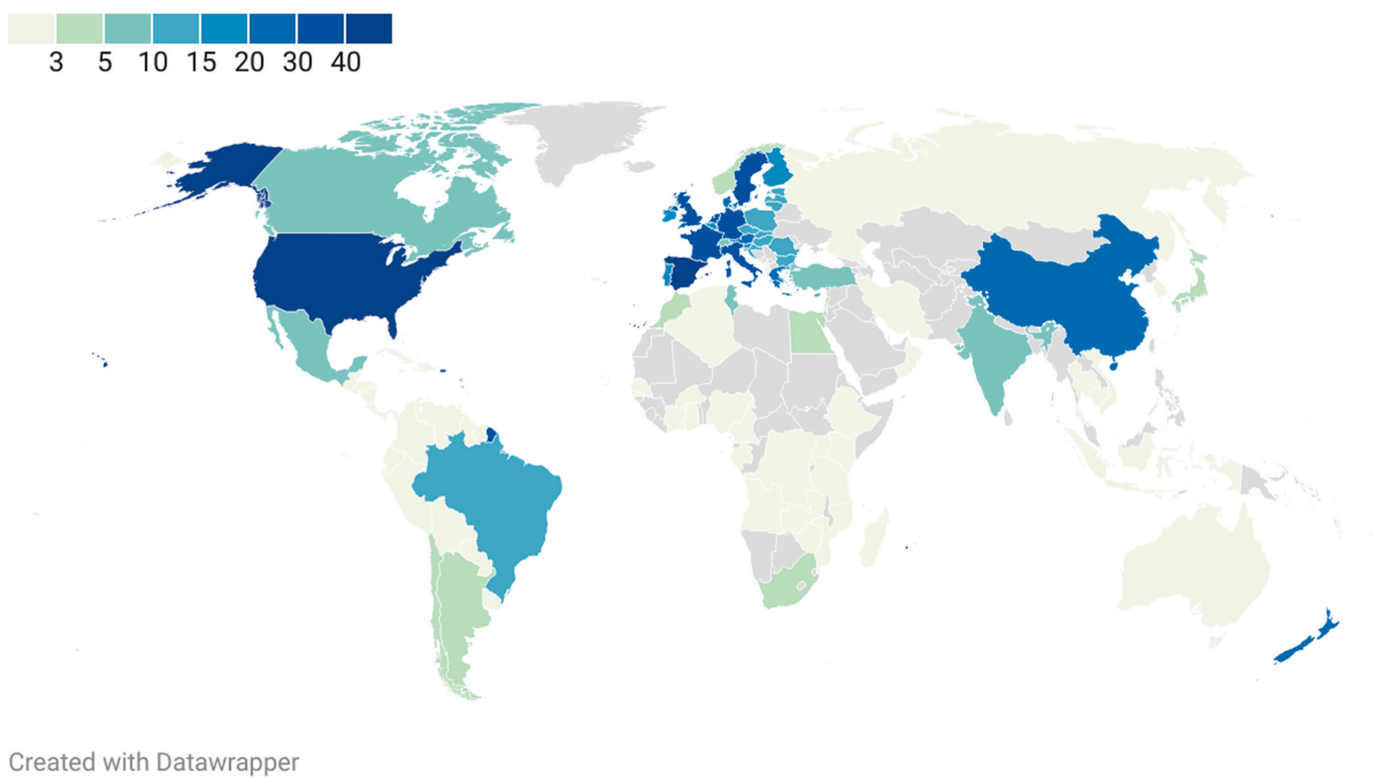

Fig. 3. Frequency of results p**er country** (n = 278, thus excluding studies that assessed more than 50 different countries, or no countries). Darker areas represent those countries that are most frequently studied. The top ten countries assessed are United States (5.41 % of 278 papers), Spain (5.16 %), United Kingdom (4.53 %), France (4.4 %), Italy (4.4 %), Netherlands (4.15 %), Sweden (3.9 %), Germany (3.9 %), Denmark (3.52 %) and China (3.27 %). The grey areas represent countries for which no studies were found. Visualisation created using datawrapper. de.

assessment. About 14 % used data collected at the household level, such as expenditure data. The population approach was used to estimate diets in 31 % of the papers, with the majority using food supply (or availability) data such as the FAO Food Balance Sheets.

3.2.2. Environmental concerns addressed

The environmental indicators used in each of the papers were categorised in overarching indicator groups representing environmental concerns such as climate change, water use or nitrogen and phosphorous flows (Table S3). Fig. 4a shows how frequently each environmental concern was addressed. More than three-quarters of the papers considered the impacts of diets on climate change; the second and third most common environmental concerns considered were water and land scarcity/use. This is in line with previous reviews on this topic (Aldaya et al., 2021; Auestad and Fulgoni, 2015; Heller et al., 2013; Jones et al., 2016; Lu and Halog, 2020; Mertens et al., 2017; Reinhardt et al., 2020; Ridoutt et al., 2017). About 50 % of the papers reviewed addressed only one environmental concern, with 62 % addressing climate change, 25 %

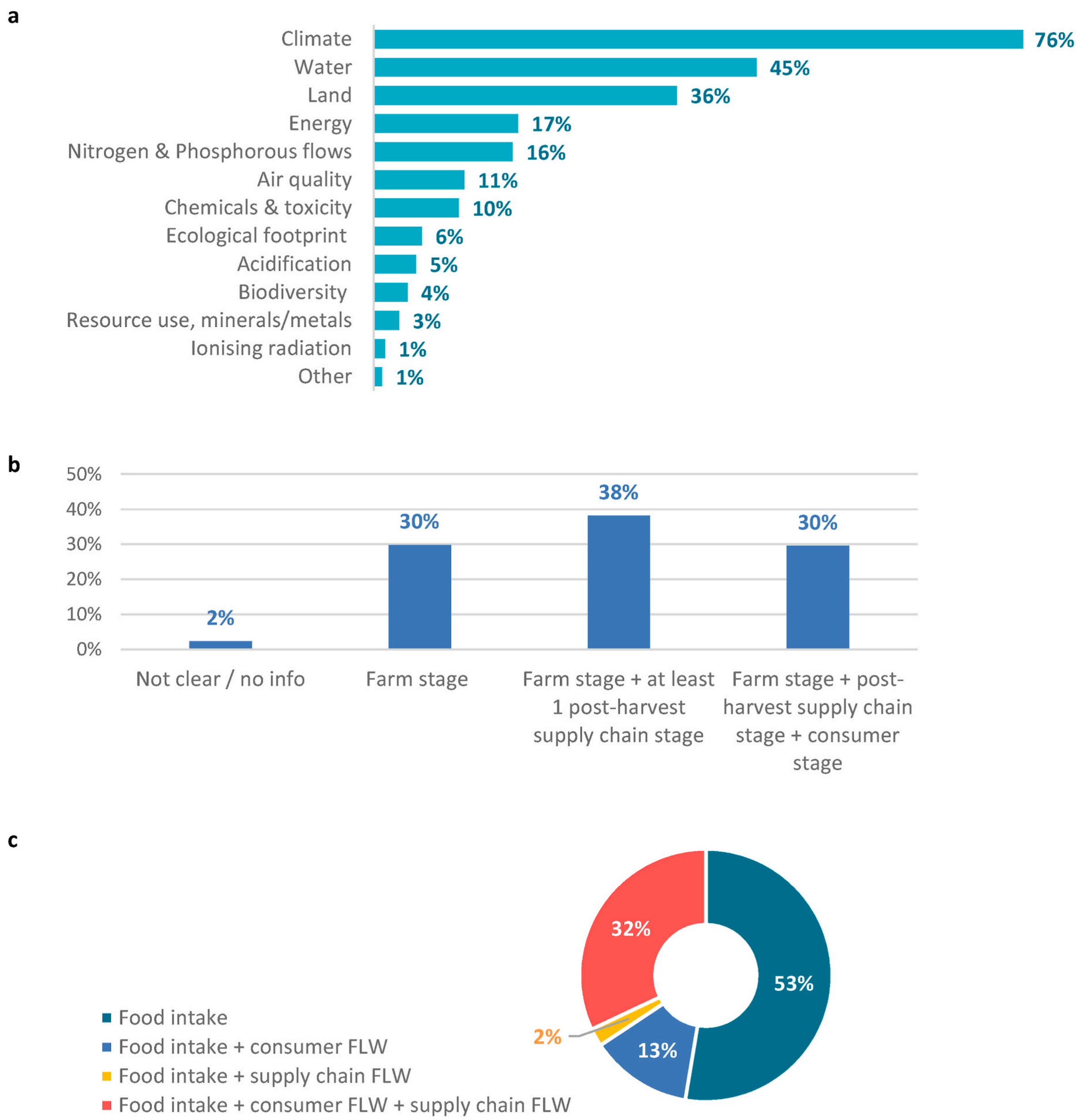

Fig. 4. Methodological decisions underlying the calculations in the 301 studies reviewed. a. Environmental concerns addressed: proportion of papers examining indicators belonging to each environmental concern. As several environmental concerns may be addressed in one paper, the percentages do not add up to 100 %. b. Frequency of life cycle stages included in the system boundaries of the environmental assessment. c. Frequency of data quantities used to formulate a diet, indicating which ones included consumer and/or supply chain food loss and waste (FLW).

addressing water use/scarcity and 7 % addressing land use/scarcity. About 17 % and 15 % of the papers calculated impacts for two and three environmental concerns respectively, and only 18 % of the papers considered four or more environmental concerns.

3.2.3. Life cycle stages included in the system boundaries

Often more than one type of system boundary was considered within a single paper, for example according to the environmental concerns studied. In many cases, multiple background studies (each employing distinct methodologies) or databases were utilised for the various foods or food groups present in a diet. Since analysing each of the background studies was out of scope of this review, the system boundaries were concluded to be unclear. When it comes to the databases though, the manuals or methods description of the databases provided some insight into the system boundaries. This was the case, for example, for studies that made use of the SHARP indicators database (Mertens et al., 2019), the SU-EATABLE LIFE database (Petersson et al., 2021), the Barilla Double Pyramid model (BCFN, 2016), the footprints of foods consumed in Brazil (Garzillo et al., 2020) or the Netherlands (Marinussen et al., 2012), the Water Footprint from Mekonnen and Hoekstra (2011a), the Agribalyse database (ADEME-INRAE, 2022), or global meta-analyses (Clune et al., 2017; Poore and Nemecek, 2018).

Fig. 4b shows how frequently each system boundary approach was chosen (more details in Supplementary Table S5), with the results being grouped into papers focussing on the farm stage only, papers studying the farm stage and at least one post-harvest stage, and papers studying all stages up until the consumer stage. Finally, a fourth category depicts those papers for which the studied life cycles could not be determined. A cradle-to-farm approach was used in 30 % of cases, resulting in the exclusion of all impacts generated in the post-harvest chain. Supply chain stages other than the farm stage were considered in 38 % of cases. However, a few papers omitted certain stages of the supply chain such as processing or point of sale, and therefore do not represent a complete assessment of the supply chain. Few papers were clear about packaging. The consumer or use stage was included in 30 % of cases. Of these, more than half were not really clear whether transport by the consumer was included or not. In addition, about a third were not clear whether this meant that food storage and/or preparation was included in the assessment. About a third of the papers that looked beyond the supply chain stage also included the end-of-life or waste stage, i.e. the treatment of food waste (such as composting or incineration) and/or packaging waste. Three papers even considered human metabolism. For eight papers it was not possible to identify the system boundaries.

3.2.4. Accounting for food loss and waste (FLW)

The selected dietary data source determines the food quantities included in the analysis (Supplementary Table S6). Individual data, such as nutrition survey data or modelled diets, only consider what is actually eaten, thus ignoring food purchased and wasted as well as food lost along the supply chain. Household-level expenditure data, on the other hand, include information on both the food that is eaten and the food that was purchased but never eaten. Therefore, this data may overestimate actual food intake. Population-level data on food availability go one step further and also include food that is lost or wasted along the food supply chain. The present review has shown that some papers adjusted the food quantities included in the dietary data to include consumer and/or supply chain FLW before proceeding to the environmental assessment. However, some papers decided to do the opposite and actually subtracted FLW from the dietary data quantities. In most cases, this is done by using global or national data on FLW quantities, such as FAO FLW data (Gustavsson et al., 2011) or national statistics on FLW. Berners-Lee et al. (2012) went one step further by comparing the FAO food availability data for the UK with the self-reported food intake data to calculate FLW quantities. Two studies (Song et al., 2015; Souissi et al., 2022) went even further and made a special effort to collect consumer FLW data at individual/household level during the data collection process. Blas et al. (2018) also used FLW data collected at household level, but using a different household sample as the one used for determining food expenditure. Following these adjustments, the majority of assessments are now based on food intake quantities (53 %, Fig. 4c), followed by food intake quantities complemented with both consumer and supply chain FLW quantities. To a lesser extent, food intake quantities complemented with only one FLW stream (consumer FLW or supply chain FLW) were used. As a result, supply chain FLW was included in the food quantities underlying 34 % of environmental calculations (and excluded in 66 %), whereas consumer FLW was included in 45 % of cases (and excluded in 55 %).

FLW can also be included in the environmental impact calculations themselves. This is done by assuming that a larger amount of food is introduced upstream in the food chain to account for FLW, for which the relevant life cycle impacts are also considered. As few studies clearly reported on this, it was not possible to analyse whether and how FLW was included in the environmental assessments performed in the reviewed papers.

While most studies that appear to have considered food waste present the environmental impacts associated with both consumed and wasted/lost food quantities as a whole, some studies explicitly show which impacts are attributable to the food actually eaten and which are attributable to the food discarded by the consumer and/or along the supply chain (Birney et al., 2017; Blas et al., 2018; Conrad et al., 2018; Conrad et al., 2020; Eberle and Fels, 2016; Heller and Keoleian, 2014; Song et al., 2015; Wang et al., 2020).

3.2.5. Data granularity: focus on modern (plant-based) diets

When it comes to the data collection process, concrete information on which exact food items were considered is not often provided for. For diets based on food availability from the FAO Food Balance Sheets, we can expect the data to cover about 75 food commodities as shown on the FAO website (FAO, 2024), including single items such as “bananas” or grouped items such as “lemons, limes and products”. Food expenditure and food intake data tend to result in highly granular data with studies reporting for example the use of a 136-item food frequency questionnaire (FFQ) (Fresán et al., 2018) or a 376-item food expenditure survey (Arrieta et al., 2021). Food diaries or 24/48 h recalls, in which respondents note or recall every single food they consume or have consumed, can be even more detailed, with over 500 items reported by for example Bozeman et al. (2020) or an unlimited number of food items to report on, as also mentioned by Mertens et al. (2017). Without access to the actual questionnaire or to the collected data, the level of detail of each data collection process, and whether modern foods were considered, remains unclear. Furthermore, often a lot of detail gets lost as the dietary data is often processed and aggregated, before moving onto the next step of the process, namely linking the foods with environmental impact data. When it comes to this environmental data, there are also great differences to be found. Highly granular environmental impact data can be found in global meta-studies and in environmental impact databases (see also Table 3 in the discussion section). However, not all of them include (sufficient) DFs or MDS. The supplementary file from Clune et al. (2017) for example, includes almond and soy milk, but no meat alternatives and no DFs such as sweets and bakery products. The SHARP indicators database (Mertens et al., 2019) on the other hand includes MDS such as tofu, soy yoghurt and several confectionary products. Nevertheless, besides tofu, no other meat alternatives were found. This in contrast to the Agribalyse 3.1 database (ADEME-INRAE, 2022) which includes a wider range of MDS and DFs.

Unfortunately, most of the reviewed studies did not report on how the dietary data were linked to the environmental impact data and if, for example, proxies were used. Moreover, only few studies provide explicit information on whether DFs or MDS were considered. Also, approaches and definitions of DFs may differ. We found that DFs were included in a number of studies on Australian (Hadjikakou, 2017; Hendrie et al., 2014, 2016, 2022; Ridoutt et al., 2019, 2020, 2021a–c, 2022) and Swedish (Hallström et al., 2021, 2022) diets. In the case of MDS, none of the reviewed papers were particularly clear about whether these products were included in the data collection instrument. Due to the processing that many DFs and MDS have undergone, they are often classified as (ultra)processed foods in the NOVA classification system (Monteiro et al., 2018). The extent of processing and how this affects the environmental impact of a diet has been investigated in the Adventist community in USA and Canada (Berardy et al., 2020), in Brazil (Da Silva et al., 2021; Garzillo et al., 2022) and in the Netherlands (Vellinga et al., 2022). Other papers explicitly mentioned that ultra-processed foods “were excluded from the analysis due to the lack of reliable environmental footprint data” (Arrieta et al., 2021). Although many papers did not clearly indicate whether DFs or MDS were included in the dietary data collection and/or environmental impact sources, this does not necessarily mean that they were excluded. Nevertheless, the review remains inconclusive as to whether the tools used really allowed modern diets to be captured and subsequently assessed.

4. Discussion

4.1. A heterogeneous, incomplete and untransparent approach

Our analysis showed that about half of the papers calculated impacts for only one environmental concern, most often climate change. The latest update of the planetary boundaries framework (Richardson et al., 2023) found that six out of nine boundaries have already been transgressed. According to the EAT Lancet Commission, the processes and systems most affected by food production are climate change, biodiversity loss, land-system change, freshwater use, and nitrogen and phosphorus flows (Willett et al., 2019). According to the EU consumption footprint platform, ecotoxicity and particulate matter impacts would also be highly relevant for the food system (EC-JRC, 2023;

Table 3
Main characteristics of the environmental data sources used: focus on those databases and meta-studies most often referenced to (in chronological order).

Database or meta-study	Environmental themes/indicators	System boundaries	Number of food products	Geographical focus	Format and application possibilities
Water Footprint (Mekonnen and Hoekstra, 2011a, 2011b, 2011c)	Water footprint	Cradle-to-processing	ca. 150	Global	PDF (total impacts)
Foods consumed in the Netherlands (Marinussen et al., 2012)	Climate change, Land use, Fossil energy use	Farm to fork	254	Netherlands	Not clear
Barilla Double Pyramid model (BCFN, 2016)	Carbon footprint (CF), Water footprint (WF), Ecological footprint (EF)	Cradle-to-grave	240 (CF), 152 (WF), 145 (EF) In total, there are 1457 data records with often multiple data records per food item.	Global	Excel sheet (total impacts)
Clune et al. (2017)	GHG	Cradle-to-distribution	168 In total, there are 1718 data records with often multiple data records per food item.	Global	Excel sheet (total impacts)
Poore and Nemecek (2018)	GHG, Land use, Water use, Acidification, Eutrophication	Cradle-to-retail	43 food categories, with a total of over 2500 data records.	Global	Excel sheet (total impacts; individual life cycle stage impacts given for some foods).
SHARP indicators database (Mertens et al., 2019)	Climate change, Land use	Farm to fork	944	EU (in particular DK, CZ, IT, FR)	Excel sheet (total impacts); foods coded using FoodEx2
The footprints of foods consumed in Brazil (Garzillo et al., 2020)	Carbon footprint (CF), Water footprint (WF), Ecological footprint (EF)	Farm to fork	985	Brazil	Excel sheet (total impacts)
SU-EATABLE LIFE database (Petersson et al., 2021)	Carbon footprint (CF), Water footprint (WF)	Cradle-to-retail	323 (CF); 320 (WF)	Global	Excel sheet (total impacts)
Agribalyse 3.1 (ADEME-INRAE, 2022)	The 16 PEF indicators (climate change, water use, land use, eutrophication, …), as well as the aggregated single score PEF	Farm to fork (possibility to apply other system boundaries)	2517	France	Excel sheet (total impacts; impacts for each individual life cycle stage); full version to be accessed using LCA software. Foods coded using CIQUAL.

European Commission, 2024). Given the many aspects that are relevant for food and agriculture and given the transgression of several planetary boundaries, focussing on one single environmental concern may be seen as problematic. Furthermore, it may result in certain environmental trade-offs going unnoticed. For example, a healthy diet may be associated with less agricultural land use than a less healthy diet, but with greater use of pesticides and irrigation water (Conrad et al., 2020). Similarly, a dietary shift to an increased intake of fruits and vegetables may result in higher blue water use (Wood et al., 2019). Dairy substitutes all have a lower carbon footprint than dairy milk. However, within the category of dairy substitutes itself, impacts across various impact categories may vary (Ritchie, 2022b). Focussing only on greenhouse gas emissions would not make these trends and within-product-category differences visible.

We also found that the consumer stage was only included in 30 % of cases, resulting in an underestimation of the calculated dietary impacts in the remaining 70 %. For example, vegetables have low impacts at the farm stage, but can have relatively high impacts during storage and preparation. As vegetables make up a large part of a healthy plant-based diet, it would be worth investigating how the inclusion of the consumer stage affects the overall impact of a diet and whether there are differences between dietary patterns. To find out if a sole focus on the agricultural or farm stage of a food product would be a valid approach, we carried out a quick check of the environmental database Agribalyse 3.1 (ADEME-INRAE, 2022) to get a better understanding of the magnitude of post-harvest supply chain and consumer stage impacts. The quick analysis, as presented in Supplemental note 3 (Fig. S2 and Table S7), shows that for 35 % of the products within the database, the contribution of the farm stage to a food products' total climate impact is less than 50 %. There is however a difference between the various food categories, with the farm stage often being more important for animal-based products than for plant-based products. For fruits and vegetables, the farm stage contributes to about 39 % of the climate change impact whereas the consumer stage was sometimes found to contribute up to 20–30 % of the total life cycle climate change impacts. For meat, egg and fish products on the other hand, the farm stage contributes to, on average, 79 % of the climate change impact. In fact, the farm stage impacts exceed 50 % of the food chain impacts for 81 % of the products of that food category, whereas for fruits and vegetables, this is the case for only 27 % of the products. Similar conclusions can be made for the aggregated PEF score. It was out of scope of this paper to provide for a full analysis of the Agribalyse dataset, both in terms of foods included in the database and assumptions taken by Agribalyse on how to model all processes, as well as in terms of the impact values for other environmental indicators. Also out of scope was an assessment of how important each of the products would be, as not all products within the database are being eaten in the same quantities and would thus not receive the same weight within a dietary assessment. Nevertheless, the quick analysis has shown the importance of including post-harvest stages into the assessment as leaving out of a part of the supply chain and/or of the consumer stages would result in an underestimation of the actual dietary impacts. The inclusion of post-harvest stages would be particularly relevant when comparing dietary patterns where differences in the consumption of animal-based and plant-based foods are key. Furthermore, excluding certain life cycle stages may mask any trade-offs that may exist between life cycle stages. Omission of a part of the supply chain would further hide improvements in supply chain resource efficiency, which is an important step in moving towards a more sustainable food system. The need to include post-harvest stages in the assessment, rather than just focussing on the farm stage, has also been highlighted by others (Hallström et al., 2015).

Various papers made use of environmental databases or meta-studies to obtain the per kilogram impacts of the foods included in the diet. The methodological considerations underlying the calculations of the impact values included in these data sources can be very different, for example in terms of system boundaries, environmental concerns covered and number of food products included in the dataset. This is illustrated in Table 3 for a selection of data sources frequently used in the studied papers. Also, the geographical focus of the databases tends to differ with some providing a global scope, while others focus on one single country. The way the impact values can be extracted from the databases varies as well. Whereas most sources provide for an excel sheet with the total chain impacts (corresponding to the selected system boundary), two of them allow (to some extent) for a more detailed insight into the impacts of individual life cycle stages. Moreover, Agribalyse provides for a so-called full version of the database which can be imported into LCA software to see each and every subprocess within each life cycle stage, after which LCA software users can also modify the data records if needed.

The choice of dietary data used to formulate a diet determines the quantities of food included in the diet studied. Some inherent problems arise as a result of the choice of dietary data source, leading to overestimation or underestimation of the food quantities consumed (Supplementary note 4). In addition, not all dietary data sources are able to capture modern diets. For example, food availability data - used in about 30 % of the reviewed studies - represent the agricultural commodities made available to the economy (for human consumption) and thus refer to foods and ingredients before processing into DFs or MDS. Hypothetical or modelled plant-based diets, formulated for example on the basis of dietary recommendations, often assume that meat (and dairy) products are replaced by unprocessed fruits, vegetables, pulses and nuts (Hallström et al., 2015) and do not include processed MDS. Along the same lines, studies assessing the environmental impacts of our diets often do not, or only incompletely, include DFs (Hadjikakou, 2017; Hallström et al., 2018; Seferidi et al., 2020). Given their large contribution to environmental impact (Carlsson-Kanyama et al., 2003; Hadjikakou, 2017; Hallström et al., 2022; Hendrie et al., 2014, 2016) , omitting DFs, MDS and other (highly) processed foods will lead to an underestimation of the real impact of our diets. Furthermore, it would be important to distinguish exactly which MDS are eaten, as the impacts can vary significantly and there may be trade-offs between impact categories (Ritchie, 2022a, 2022b; Smetana et al., 2023). For modern foods, another difficulty is that some environmental databases lack products that can represent these DFs or MDS. Dietary data collection tools are often based on a larger number of foods than the environmental impact databases used to calculate the associated impacts (Mertens et al., 2017). This is particularly the case for food intake data in which an infinite list of foods may be considered and which therefore may include a wide range of modern foods. As a result, proxies need to be identified that can adequately represent these modern foods in the environmental impact datasets. Using food classification codes in both the dietary data and in the environmental impact data would facilitate matching both datasets (Ferreira de Sousa et al., 2020; Furrer et al., 2024; Reynolds et al., 2022). In this context, it is important to highlight some best practices in this field. For example, as shown in Table 3, all foods from the Agribalyse environmental database are coded using the Ciqual code from the French Ciqual nutritional composition table (ADEME-INRAE, 2022; ANSES-CIQUAL, 2020), and all foods from the SHARP indicators database (Mertens et al., 2019) are coded using the FoodEx2 standard, which is the EU food classification standard from EFSA (EFSA, 2015). Moreover, in 2021, EFSA launched a call for tender for creating an open access EU food composition database (mapped to FoodEx2), which is to be linked with an environmental footprint of food database (EFSA, 2021).

Whether or not food quantities associated with supply chain or consumer FLW are included in the dietary data also affects the dietary impact calculations. Our review showed that data representing food availability quantities, including both supply chain and consumer FLW, were used in 32 % of the assessments, whereas food intake quantities were used in 53 %. Literature suggests that food intake data (excluding FLW amounts) should be used to assess dietary nutrient intake or other health aspects, and food availability data (including FLW amounts) should be used to calculate the environmental impact of a diet (Hallström et al., 2015; Heller et al., 2013; Mertens et al., 2017). However, we postulate that caution is needed with this suggestion. If a study were to consider FLW in impact calculations, this would mean that an additional amount of food would be assumed to travel through upstream life cycle stages to account for this FLW. How this would then interact with dietary data that already includes FLW amounts is not straightforward. For example, if a study is based on data representing food availability quantities, this means that impacts are calculated for a quantity of food that includes both the food that is eaten and the food that is lost and wasted along the supply chain and at the consumer. If the chosen impact calculations follow a cradle-to-retail approach and consider upstream FLW, this means that impacts are calculated not only for these food availability quantities, but also for additional food quantities that are assumed to move through the food chain. This is not realistic as such additional food quantities do not exist and the resulting impacts will overestimate the real dietary impacts. In this case, it may be prudent not to include FLW in the assessment itself, as it is already included in the dietary data. Or vice-versa, one could advise to use dietary data which excludes FLW. A thorough analysis of this issue was beyond the scope of this review, but it seems that the interplay between dietary data, system boundaries and the inclusion of FLW would be an interesting avenue for future research.

The review highlighted significant variability in approaches applied in the 301 papers, which impairs the comparability of the results. A first issue lies with the choice of dietary data on which the diet is built, and whether or not supply chain and/or consumer FLW are included in the food quantities covered by the diet. A second issue lies with the choice of system boundaries, which determines which life cycle stages contribute to the impact of a diet. Third, the decision on whether or not supply chain and/or consumer FLW are considered when calculating impacts matters. Fourth, both the dietary data collection instrument as well as the environmental impact sources or databases will determine the extent to which DFs and MDS are covered. These four factors will together determine the magnitude of the calculated impact of a diet. Any comparison of findings would thus require comparable decisions being made on these aspects as also highlighted by others (Auestad and Fulgoni, 2015; Hallström et al., 2015). Furthermore, any wrong decision would most probably lead to an under- or overestimation of the calculated dietary impacts.

The analysis also showed that the methods section of the papers reviewed was often vague or incomplete. Only for the calculated environmental indicators was information readily available in all 301 papers. Many papers do not provide explicit information on the type of dietary data collection tool that was used and whether the food quantities collected included FLW. Information on the system boundaries used and whether and how FLW were taken into account in the impact calculations is important, but often not reported in the reviewed papers. Often several background studies (each with its own specific methods) or databases were used for the different foods or food groups in a diet, making it impossible to analyse each of the methods used. Where necessary, additional information was sought in other publications. Still, despite this thorough search, some information could not be found. Furthermore, when authors claimed to have included FLW in their assessment, it was often not stated whether FLW was included in the environmental impact calculations or in the dietary data. However, these choices would greatly influence the magnitude of the impacts associated with the diet or dietary pattern studied. Finally, when it came to which foods were included in the analysis, it was not always clear whether DFs or MDS were included. Although it is not reasonable to expect studies to report on *all* foods included in the dietary data collection process and/or environmental impact assessment, more transparency on these so-called modern foods would be desirable.

The multitude of methodological decisions (passive or active) made by researchers in calculating the environmental performance of diets may be attributed to the interdisciplinary nature of this field of research. A researcher specialising in public health and nutrition may be fully aware of the consequences of methodological decisions related to dietary data and may actively make certain decisions, whereas they may be less familiar with methodological decisions related to calculating environmental impacts. In the event that the researcher utilises existing studies and/or databases to calculate the impacts, it is likely that they would assume the underlying assumptions to be valid and that there is no need to question their suitability for the specific study they are undertaking. Along the same line, this researcher might not be aware of the diversity there is amongst environmental databases (see Table 3) or other secondary data. Conversely, a practitioner of life cycle assessment may lack familiarity with decisions related to dietary data. It is probable that they would utilise dietary data that is readily available, without questioning the representativeness or appropriateness of the data.

4.2. Limitations of our research

A limitation to the approach taken in this paper, refers to the literature search strategy, as only one single search database was used. To improve the comprehensiveness of this study, multiple databases could be searched in future reviews. We however note that the snowballing step of the literature search allowed us to include a further 183 papers to the 4537 papers already identified in the database search, resulting in a total of 301 papers being analysed in detail. The authors believe the combined set of papers found using this approach would already present quite a representative share of literature on the assessment of the environmental impact of diets. The fact that 301 papers were retained for the analysis could at the same time also be seen as a limitation, as this severely affected the time needed to perform this review. As a result, by the time the review study will be available to the public, many more papers will have been published on this matter which could not be included in this present review (which considers papers published up until December 2022).

A next limitation lies in the fact that this paper addresses researchers from two disciplines, as explained in the introduction section. We therefore decided it was preferable to focus on only a few methodological decisions, which were assumed to be comprehensible to researchers from both disciplines. Within the area of life cycle assessment, this means that for example decisions related to the allocation of impacts for multi-functional products, or related to which exact indicators or impact assessment methods were used for each of the investigated environmental concerns, were not investigated. We however believe our review presents a first step in creating awareness regarding methodological decisions for both research disciplines involved. Moreover, a more comprehensive grasp of these challenges could enhance the transparency of methodology reporting.

Another limitation lies with the scope of this paper. A recent development in the life cycle assessment of diets is the integration of nutritional quality and health effects of foods, resulting in a nutritional LCA. This approach allows researchers to extend their scope from a merely environmental one to one that also incorporates health effects. The last few years, a lot of literature has been published on this matter (Bianchi et al., 2020; FAO, 2021; Jolliet, 2022; Ridoutt, 2021; Saarinen et al., 2017; Strid et al., 2021). The present review paper is limited to the environmental performance of diets, without nutrition or health effects. Effects in the dimensions of economy and society, as well as animal welfare and health, would also need to be addressed for a sustainability assessment. This review paper presents a first step towards an encompassing analysis of methodological choices relevant to all dimensions of sustainability.

5. Conclusions and recommendations

The present review looked into methodological decisions within each of the two disciplines (public health and nutrition, and environmental sciences and life cycle assessment) that are relevant for calculating the environmental performance of diets. The review has shown that most studies that calculate the environmental performance of a diet have a narrow focus, with 50 % looking at only one environmental concern, most commonly climate change. In addition, most studies do not include all life cycle stages in the assessment. Only 30 % of the cases considered the impact at the consumer stage. While it was clear that the majority of the papers used food intake data which does not include FLW, it remains unclear how exactly FLW was dealt within the environmental assessment itself. It was also unclear which papers were able to include DFs and MDS to reflect modern diets.

The wide range of methodologies used in the reviewed papers makes it difficult to compare the results. In addition, not all methods can be correct as some methodological choices lead to under- or overestimation of the calculated dietary impacts, or hide trade-offs between impacts in different impact categories and/or life cycle stages. A more harmonised and comprehensive approach would make it easier to compare results, improve the potential of these assessments to provide environmental dietary guidance, and allow us to set benchmarks and properly assess progress towards a more environmentally friendly diet such as the Planetary Health Diet.

From the analysis presented in this review paper, several recommendations can be derived, as summarised in Fig. 5. To start with, the assessment should go beyond climate change effects of a diet and also include impacts related to water and land use, pesticide use (such as ecotoxicity impacts), nitrogen and phosphorus flows, particulate matter and biodiversity. Next, the assessment should cover the whole food chain, up to consumption, thus including also consumer storage and preparation impacts. Furthermore, appropriate granularity in both the dietary data sources and the environmental databases is needed to ensure all consumed foods, including modern foods, can be adequately linked to environmental impact data.

In addition to the diversity in methods used, there is also a great diversity in how studies report on the methods used. It can be concluded that authors are not always transparent about the methodological choices made. We therefore call for greater transparency on the assessment of the environmental performance of diets. It is our contention that our review paper will contribute to this endeavour by fostering greater awareness of the significance of the diverse methodological decisions that are being actively and passively undertaken by researchers.

The creation of an environmental database for food, based on harmonised and transparent standards, or a standard for secondary data to be used for dietary assessments, would represent an important next step in this direction. In this way, the responsibility of making methodological decisions regarding the environmental assessment is being centralised and not left to each individual researcher. It would be preferable for such a database to include a wide range of environmental concerns as mentioned above (including guidance on which methods and indicators to use for each environmental concern), to be based on a farm-to-fork approach, and to encompass a diverse range of modern foods. The existing databases and meta-studies listed in Table 3 are already a first step in the right direction. However, there is a need for harmonisation. Next, we suggest providing researchers with more guidance on how to best link dietary data with environmental impact data. In this context, we recommend both the foods included in the dietary data and in the environmental impact datasets to be coded using commonly used food classification systems such as the FoodEx2 standard.

Finally, we identified several research gaps. An interesting avenue for future research would be to look more closely at the interplay between the chosen dietary data source, how impacts are (or can be)

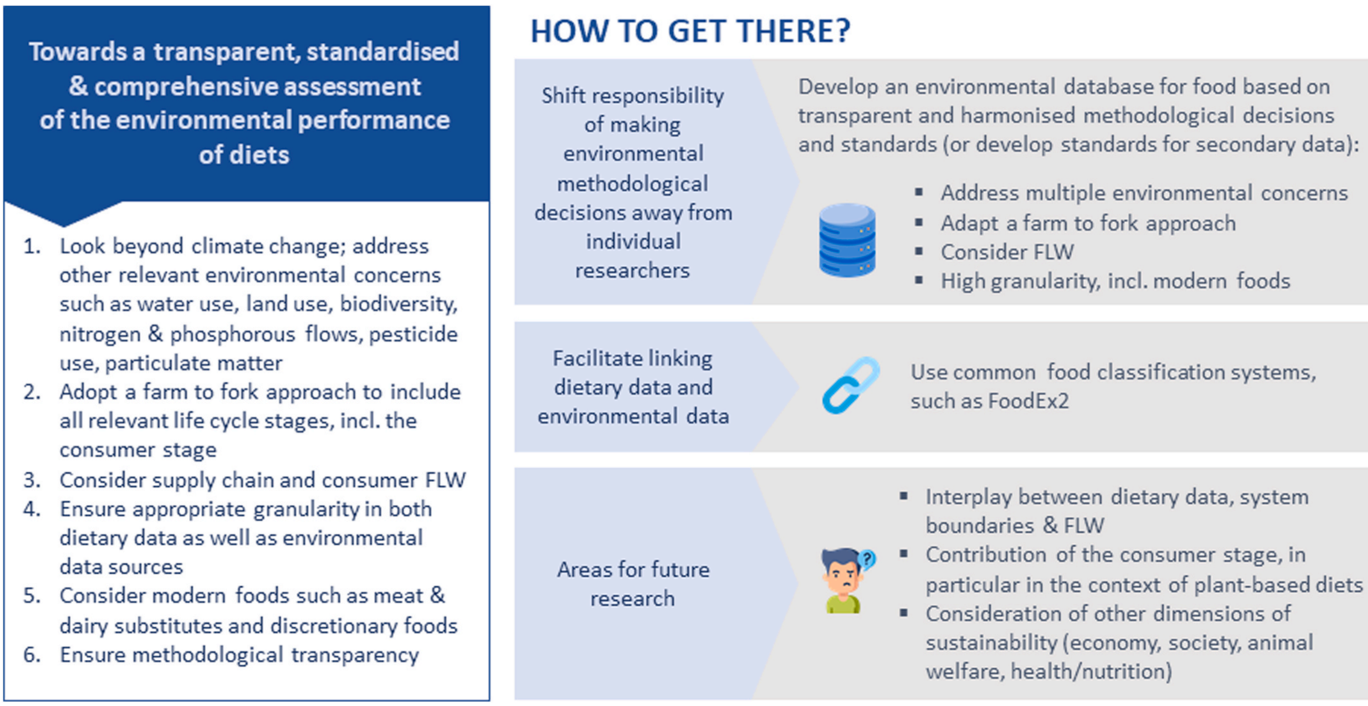

Fig. 5. | Main recommendations resulting from the review, including ways to get there.

calculated and how FLW is addressed in both of these steps. It would also be interesting to explore the contribution of the consumer stage in real-life (plant-based) diets and whether there are differences between dietary patterns. Furthermore, as a sustainable diet goes beyond environmental sustainability, it would be interesting to see if and how each of the reviewed studies addresses other dimensions of sustainability (economic, social, animal welfare, and health/nutrition), including which ones applied a nutritional LCA, and how all dimensions can be investigated simultaneously. Such a multi-dimensional approach is needed to assess progress in our transition towards a food system within a safe and just operating space.

CRediT authorship contribution statement

Yanne Goossens: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Thomas G. Schmidt:** Writing – review & editing, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used DeepL Write in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements and funding sources

This paper was written using the internal budget from the Thünen Institute, within the context of the German COPLANT project (Cohort-Study on Plant-based Diets). The funder of the project had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2025.100289. Multimedia Component 1 contains Supplementary Tables S1-S7; Supplementary Figures S1-S2; Supplementary notes 1-4; Multimedia Component 2 contains Supplementary Table S8.

Data availability

All data used for the purpose of this review is provided for in the Suppplementary files.

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