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CRITICAL REVIEW

Towards an aligned nutritional and environmental impact assessment: a state-of-the-art review

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Abstract

Purpose While nutritional life cycle assessment (n-LCA) aims to integrate health and environmental sustainability, the compatibility of underlying data and methodological choices remains unclear. So, this study critically evaluates whether nutritional and environmental dimensions are methodologically adequate and aligned in n-LCAs. We assessed the consistency of functional units, system boundaries, data sources, geographic representativeness, and characterization methods to identify key misalignments and provide recommendations to improve robustness, comparability, and policy relevance.

Methods A narrative scoping review was conducted on peer-reviewed n-LCA studies published between 2014 and June 2024. Articles were identified through reference mining, snowballing of prior reviews, and searches in PubMed and Scopus. Data extraction covered general characteristics, environmental assessment features (functional units, system boundaries, life cycle inventory sources, impact categories, characterization methods), and nutritional assessment features (nutritional indicators, food composition databases, preparation stage). Methodological alignment was qualitatively evaluated across three domains: (i) consistency between study context and environmental assessment, (ii) consistency between study context and nutritional assessment, and (iii) cross-dimensional compatibility. Alignment was categorized as full, partial, or absent based on predefined criteria.

Results and discussion Twenty-three studies met inclusion criteria. Substantial methodological heterogeneity was observed. Mass-based functional units predominated, though energy- and nutrient-based units are increasing. Many studies relied on heterogeneous or poorly documented environmental datasets, often without transparent characterization methods. Climate change was assessed in all studies, whereas other impact categories were inconsistently reported. Nutritional assessments frequently used national food composition databases, yet 35% were partially or fully geographically misaligned. Cross-dimensional inconsistencies were common, particularly regarding system boundaries (e.g., farm-gate environmental data versus ready-to-eat nutritional data), product scope, and geographic representativeness. These structural mismatches limit comparability, increase uncertainty, and risk misleading conclusions about health–environment synergies or trade-offs.

Conclusions Although n-LCA holds strong potential to inform sustainable diet transitions, current practice remains fragmented due to methodological misalignments across study context, and the nutritional and environmental dimensions. Improved transparency, geographically coherent data, harmonized scope, and integration of health-outcome metrics are essential to enhance validity and policy relevance.

Keywords Sustainable diets · Nutrition assessment · Life cycle assessment · Methodological alignment · Environmental impact

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1 Introduction

Contemporary dietary patterns, characterized by high consumption of added and free sugars, salt, unhealthy fats, and certain animal-derived products, are closely linked to the growing global burden of non-communicable diseases (NCDs), including obesity, type 2 diabetes, cardiovascular diseases, and certain cancers (GBD 2017 Diet Collaborators 2019). Simultaneously, current food systems are significant contributors to environmental degradation, including climate change, biodiversity loss, and land use (LU) changes (Poore and Nemecek 2018; Rockström et al. 2025). Given the urgency of addressing these challenges, ensuring diets that are both health-promoting and environmentally sustainable is one of the most critical priorities of the 21st century, especially considering the need to nourish a growing global population (Springmann et al. 2018; Clark et al. 2020; Rockström et al. 2025).

To address both nutritional adequacy and environmental sustainability, recent research has advanced integrated assessment approaches, particularly nutritional life cycle assessment (n-LCA) (McLaren et al. 2021). Building on early work by Heller et al. (2013), which highlighted the need to jointly assess environmental impacts and nutritional quality, n-LCA combines life cycle assessment (LCA) methods with nutritional or health metrics to evaluate foods and diets in an integrated manner (Tilman and Clark 2014; Stylianou et al. 2016; Berardy et al. 2019; Fresán and Sabaté 2019; Batlle-Bayer et al. 2020; Jolliet 2022; Green et al. 2023; Peruvemba et al. 2025).

In recent years, the application of n-LCA methodologies has surged, accompanied by the publication of several reviews (McAuliffe et al. 2020; Reguant-Closa et al. 2024). These reviews have largely examined how to best quantify the nutritional dimension, including the selection of nutrient adequacy indices and the suitability of different methodological approaches (e.g., capping). However, an important gap remains: while prior work has emphasized the measurement of nutrition, far less attention has been given to whether the environmental and nutritional data sources, assumptions, and methodological choices within a given assessment are adequate for the study context, goal and scope, as well as mutually compatible. Such methodological alignment is essential to ensure internal consistency and to avoid biases stemming from these mismatches.

Therefore, the objective of this study was to provide a structured critical mapping of the methodological frameworks and underlying data employed to assess the nutritional and environmental dimensions in n-LCAs, with particular emphasis on the consistency and methodological alignment between each dimension and the specific context of the study, as well as between the nutritional and environmental dimensions themselves, in research assessing food products and dietary patterns. By examining the intersection of these aspects, the study sought to identify potential key gaps and misalignments in current research practices. Furthermore, it aimed to provide evidence-based recommendations to support the development and adoption of standardized approaches to enhance the accuracy, comparability, and overall reliability of future integrated assessments.

2 Methodology

2.1 Literature search

This review was conducted as a narrative scoping analysis. The literature search was initiated through reference mining from the most recent available review on n-LCA at that time (Reguant-Closa et al. 2024), which focused on diet quality indices used in environmental evaluations since 2014. Of the 18 relevant articles cited in that review, 15 were original research papers directly assessing both nutritional and environmental aspects, while three were reviews. A snowballing strategy was subsequently applied to these three reviews, resulting in the identification of 16 additional potentially relevant studies (Fig. 1).

To complement this initial pool, an updated database search was conducted using an adapted Boolean search strategy from the one reported by Reguant-Closa et al. (2024), restricted to articles published from January 2023, corresponding to the date of the latest article included in that review, to June 2024, when the current review was initiated. Searches were performed in PubMed and Scopus databases and the search string used for this study is reported in Online Resource 1. The inclusion criteria applied to the identified articles were as follows: original peer-reviewed research articles, published in English, French or Spanish, available in full text online, published from January 2023 (date of the latest article included in the review by Reguant-Closa et al. (2024) and up to the beginning of June 2024 (when the current review was initiated), and reporting both environmental impact metrics and nutritional or health-related metrics. A total of 116 studies were identified with this updated search (45 from Pubmed and 71 from Scopus), as shown in Fig. 1. After removing duplicates and applying inclusion criteria, the titles and abstracts of all identified records were screened by the primary reviewer (RCS), resulting in 4 additional articles.

To determine their inclusion or exclusion for this review, the full text of the preliminary set of 35 potentially eligible articles (15 from the Reguant-Closa review, 16 identified through snowballing, and 4 from the updated search strategy) was independently assessed by three reviewers (RCS-a

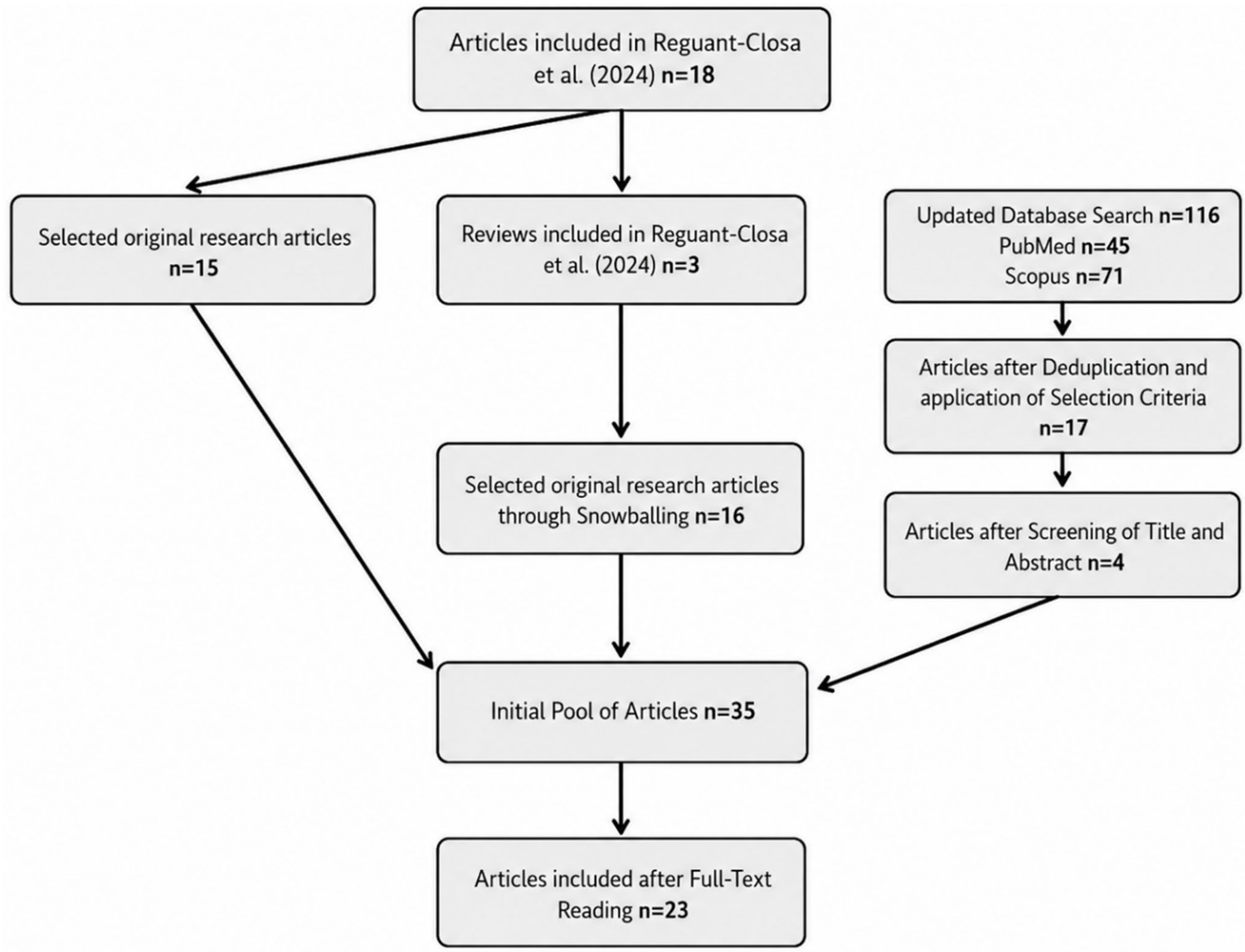

Fig. 1 Flowchart illustrates the stepwise selection process of the articles included in this review. The process combined reference mining from Reguant-Closa et al. (2024), a snowballing strategy, and an updated database search (PubMed and Scopus)

nutritionist, MRC-an LCA practitioner, and UF-with expertise in both nutrition and LCA) against the predefined inclusion criteria. Decisions were subsequently compared, and any disagreements or uncertainties raised by the reviewers were discussed on a case-by-case basis until consensus was reached. For example, disagreements arose regarding methodological studies that reported both environmental and nutritional data. Inclusion depended on whether nutrition- or health-related metrics were combined with environmental impact assessment in a single analytical framework, rather than being presented as independent evaluations. This process yielded a final selection of 23 studies (Fig. 1). The full list of the 35 preselected articles, including the 23 finally included studies and the 12 articles excluded after full-text assessment with reasons for exclusion, is provided in Online Resource 2.

Mendeley was used for bibliographic management, and the Systematic Review Accelerator (SRA) tool by the Bond University Institute for Evidence-Based Healthcare was employed to facilitate an efficient and structured review process.

2.2 Data extraction and analysis

Full-text versions of the 23 selected studies together with their supplementary materials were retrieved and thoroughly examined. Key data was extracted and organized into several dimensions to evaluate methodological alignment across studies. For each study, general characteristics were recorded, including authorship, year of publication, main study objective, geographical context, and foods or dietary patterns targeted. For the environmental assessment dimension, information on the functional units (FU), defined system boundaries, sources of life cycle inventory (LCI) data or environmental impact data, characterization methods applied, and the environmental indicators and impact categories reported were collected. For the nutritional assessment component, information on the type of indicators applied, the sources of nutritional composition data, and the preparation format of the foods (raw or cooked) were retrieved. Data extraction was performed by two reviewers (RCS and MRC) and supervised by a third author (UF) to ensure consistency and methodological rigor.

The collected data were analyzed to assess methodological alignment across three interrelated areas, reflecting how environmental and nutritional assessments were framed and integrated within each study. First, alignment between the study goal and scope and the environmental assessment was evaluated to determine whether environmental inventories, system boundaries, characterization methods, and underlying assumptions were appropriate and representative of the geographical and analytical setting defined by the study. Second, alignment between the study goal and scope and the nutritional or health assessment was assessed by examining whether nutrient composition data, dietary indicators, and health metrics were coherent with the level of analysis described in the study context. Third, alignment between the environmental and nutritional dimensions was evaluated to assess the extent to which both assessments were methodologically compatible, including consistency in system boundaries, geographic context, functional units, and key assumptions, thereby enabling meaningful cross-dimensional interpretation. For each of those pairwise comparisons, alignment was qualitatively assessed based on predefined criteria and categorized according to the level of consistency observed: full alignment (green), partial alignment (yellow), and lack of alignment (red). Full alignment was assigned when the methodological element assessed was explicitly reported and was coherent with the study context or with the corresponding element in the other dimension. Partial alignment was assigned when some degree of coherence was present, but comparability was limited by incomplete reporting, the use of mixed or proxy data sources, partial overlap in geographical scope, partial coverage of relevant life-cycle stages, or differences in food aggregation level. Lack of alignment was assigned when the methodological element was clearly inconsistent with the study context or with the corresponding element in the other dimension, or when insufficient information was provided to determine compatibility. In brief, full alignment required explicit correspondence between the assessed methodological element and the study context or the equivalent element in the other dimension; partial alignment reflected incomplete but still interpretable correspondence; and lack of alignment was assigned when the correspondence was absent, clearly inconsistent, or impossible to assess due to insufficient reporting.

The alignment assessment was conducted by the same two reviewers who led study selection (RCS and MRC). Initial independent classifications were compared, and any discrepancies or uncertainties were discussed between the reviewers and, when necessary, with the third reviewer (UF) on a case-by-case basis until consensus was reached. Major discrepancies or doubts arose particularly in cases where methodological details were insufficient or incomplete, especially when distinguishing between partial and absent alignment. For instance, disagreements arose regarding the use of environmental databases for which both regionalized and global-average data were available, when the specific dataset used was not explicitly reported. In such cases, distinguishing between partial alignment and lack of alignment required reviewer judgment based on the degree of correspondence reported in the original study. Discussions among the three reviewers contributed to resolving ambiguous cases when required.

3 Results

3.1 Overview of included studies

A total of 23 peer-reviewed studies published between 2014 and 2024 were included in this review (Table 1). All studies were written in English and primarily originated from high-income countries, with a strong focus on European contexts (n=16; 70%), particularly France, the United Kingdom, Sweden, Spain, Belgium, and The Netherlands. Additional studies examined settings in the United States (n=3; 13%) and India (n=2; 9%), while others had a broader, global scope (n=2; 9%).

In terms of study type, the majority were original research case studies (n=14; 61%) or scenario-based modelling papers (n=6; 26%) assessing the environmental and nutritional impacts of specific foods or dietary patterns. Some others consisted of methodological or conceptual papers (n=3; 13%), often proposing novel indices or hybrid frameworks to integrate health and environmental metrics.

The included studies used integrated nutritional–environmental assessments for three broad, non-mutually exclusive purposes. As some studies had more than one purpose -for instance, combining methodological development with an applied food comparison or using food-level classification to inform dietary substitution scenarios- the counts reported below overlap. First, several studies (n=13; 57%) framed their results as comparisons between individual foods, food groups, meals, protein sources, or product alternatives, aiming to identify options with more favorable combined nutritional and environmental profiles. Second, a similar number of studies (n=12; 52%) interpreted their findings in relation to dietary patterns, dietary scenarios, or dietary change, including observed diets, optimized diets, low-environmental-impact diets, or substitution scenarios designed to

Table 1 Overview of the 23 included studies

Article Information		Environmental Dimension						Nutritional / Health Dimension			
Author (year)	Geographical Context	Scope	FU	System Boundaries	Environmental Impact Indicators (units)	Characterization Method	Data sources	Scope	Food Preparation	Indicators	Data sources
Masset et al. (2014a)	France	391 most consumed foods in France	100 g food 1 Kg food	Cradle-to-Grave	Climate change (g CO2eq) Air acidification (g SO2eq) Freshwater eutrophication (mg PO3-4 eq)	Not specified	ecoinvent Others (ns)	363 most consumed foods in France	Ready to Eat	SAIN: LIM	USDA
Masset et al. (2014b)	France	391 most consumed foods in France	1000 Kcal 100 g food	Cradle-to-Consumption	Climate change (g CO2eq)	Not specified	ecoinvent Others (ns)	1314 most consumed foods in France	Not specified	PANDiet	CIQUAL
Milner et al. (2015)	UK	UK dietary pattern	1 Kg food	Cradle-to-Grave	Climate change (ns)	Not specified	Literature	UK dietary pattern	Not specified	YLL	UK Food Composition Database
Röös et al. (2015)	Sweden	3 Swedish dietary patterns	1 Kg food Yearly diet Daily diet NRD 9.3 NRD10.3 NRD 11.4	Cradle-to-Consumption	Climate change (kg CO2eq) LU (m2) Biodiversity (ns)	GWP 100-year Literature	Literature Databases in Europe	3 Swedish dietary patterns	Ready to Eat	NRD9.3 NRD10.3 NRD11.4	Swedish Food Composition Database
Perignon et al. (2016)	France	402 most consumed foods in France	Daily diet	Cradle-to-Grave	Climate change (g CO2eq)	Not specified	ecoinvent	402 most consumed foods in France	Not specified	SED MAR MER	CIQUAL
Sturtewagen et al. (2016)	Belgium	Belgian canteen meals	Serving size	Cradle-to-Grave	Resource consumption (MJ)	CEENE	ecoinvent Literature	Belgian canteen meals	Ready to Eat	NDS	NUBEL
Milner et al. (2017)	India	Indian dietary pattern	Daily diet	Cradle-to-Grave	Climate change (Kg CO2eq) WU (L)	IPCC 2013	Literature Online Calculator	Indian dietary pattern	Not specified	Kcal	IFCT
Saarinen et al. (2017)	Finland	29 most consumed foods in Finland	100 g food NRF9 FNIprot7	Cradle-to-Consumption	Climate change (Kg CO2eq)	Not specified	ecoinvent Literature LCA food database	29 most consumed foods in Finland	Ready to Eat	NRF9 NRF9.3 FNIprot7 FNIprot7.2	FINELI

Table 1 (continued)

Article Information		Environmental Dimension						Nutritional / Health Dimension			
Author (year)	Geographical Context	Scope	FU	System Boundaries	Environmental Impact Indicators (units)	Characterization Method	Data sources	Scope	Food Preparation	Indicators	Data sources
Sonesson et al. (2017)	Sweden	6 commonly consumed foods in Sweden	1 Kg food 1 g protein 1 g digestible protein 1 Kg PQI	Cradle-to-Consumption	Climate change (CO2 eq) LU (m2) Freshwater ecotoxicity (CTU)	IPCC 2013 Literature	LCA data from Swedish supply chains	3 Swedish dietary patterns	Not specified	Nutrient quantity	USDA
van Dooren et al. (2017)	The Netherlands	403 most consumed foods in The Netherlands	100 g food	Not specified	Climate change (Kg CO2eq)	CLM	Dutch Database Agrifootprint	403 most consumed foods in The Netherlands	Ready to Eat Raw	NRF9.3 NRF15.3 SNRF	NEVO
Barré et al. (2018)	France	402 foods consumed in France	Daily diet	Cradle-to-Grave	Climate change (Kg CO2eq) Atmospheric acidification (SO2eq) Marine eutrophication (Neq)	Greenext methodology Literature	Literature	4 French dietary patterns	Ready to Eat	Nutrient quantity	CIQUAL USDA
Kramer et al. (2018)	The Netherlands	208 food products Optimized Diet	1 Kg food Daily diet	Cradle-to-Grave	Climate change (Kg CO2eq) Fossil Energy Use (MJ) Land Occupation (m2)	ReCiPe 2008	Agrifootprint	Dutch dietary pattern	Ready to Eat Raw	NBC	NEVO
Berardy et al. (2019)	USA	Most common protein sources in USA	100 g food	Cradle-to-Industry	Climate change (Kg CO2eq)	Not specified	Literature	Most common protein sources in USA	Ready to Eat	Nutrient quantity	USDA
Cobiac et al. (2019)	Europe	Dietary patterns in Europe	1 Kg food Daily diet	Cradle-to-Consumption	Climate change (Kg CO2eq)	Not specified	Literature	Dietary patterns in Europe	Ready to Eat	DALYs	National Food Composition Tables
Damerau et al. (2020)	India	Indian dietary pattern	1 Kg food	Cradle-to-Farm Gate	Climate change (Kg CO2eq) WU (m3) LU (m2)	IPCC 2013 WFN & Water stress coefficient	Water Footprint Network Database Literature	Indian dietary pattern	Not specified	Nutrient quantity	IFCT USDA

Table 1 (continued)

Article Information		Environmental Dimension						Nutritional / Health Dimension			
Author (year)	Geographical Context	Scope	FU	System Boundaries	Environmental Impact Indicators (units)	Characterization Method	Data sources	Scope	Food Preparation	Indicators	Data sources
Fresán et al. (2020)	Spain	Spanish dietary pattern	1 Kg food	Cradle-to-Industry Cradle-to-Farm Gate	Climate change (Kg CO2eq) WU (L) LU (m2) Energy use (MJ)	Not specified	Literature	Spanish dietary pattern	Ready to Eat	Nutrient quantity Health risks	National Food Composition Tables
González et al. (2020)	Spain	57 most consumed foods in Spain	Daily Diet 2000Kal	Cradle-to-Distribution	Climate change (Kg CO2eq)	IPCC 2013	Literature	662 most consumed foods in Spain	Not specified	Health risks	BEDCA
Strid et al. (2021)	Sweden	118 most consumed foods in Sweden	1 Kg food 100 Kcal	Cradle-to-Industry	Climate change (Kg CO2eq)	Not specified	RISE	118 most consumed foods in Sweden	Ready to Eat Raw	NRF11.3	Swedish Food Composition Database

Table 1 (continued)

Article Information		Environmental Dimension						Nutritional / Health Dimension			
Author (year)	Geographical Context	Scope	FU	System Boundaries	Environmental Impact Indicators (units)	Characterization Method	Data sources	Scope	Food Preparation	Indicators	Data sources
Stylianou et al. (2021)	USA	167 most consumed foods in the USA	Serving size	Cradle-to-Farm	Climate change (Kg CO2eq) LU (ha) WU (m3) Freshwater acidification (kg SO2 eq) Terrestrial acidification (Kg SO2 eq) Freshwater eutrophication (kg PO4 3-Peq) Marine eutrophication (Kg N eq) Freshwater ecotoxicity (CTUe) Ionizing radiation (ns) Photochemical oxidant formation (DALYS) Fine particulate matter formation (DALYS) Cancer and non-cancer human toxicity (DALYS) Ozone layer depletion (kg CFC-11 eq) Fossil energy use (MJ) Mineral resources use (kg deprived)	Impact World+ Literature	ecoinvent World Food LCA Database ESU World Food LCA Database	5853 most consumed foods in the USA	Ready to Eat	DALYs HENI	USDA
McAuliffe et al. (2022)	Global	Global food products	100 g protein	Cradle-to-Retail	Climate change (kg CO2eq) LU (m2)	GWP 100-year	Literature	Global food products	Raw	Nutrient quantity	USDA

Table 1 (continued)

Article Information		Environmental Dimension						Nutritional / Health Dimension			
Author (year)	Geographical Context	Scope	FU	System Boundaries	Environmental Impact Indicators (units)	Characterization Method	Data sources	Scope	Food Preparation	Indicators	Data sources
Aidoo et al. (2023)	USA	Soymilk, cowmilk, soya meatballs, and beef sausage	1 Kg food 1 L food	Cradle-to-Distribution	Climate change (Kg CO2eq) Ecotoxicity (CTUe) Fossil fuel depletion (ns) Smog (kg O3 eq) Eutrophication (kg N eq) Acidification (kg SO2 eq) Respiratory effects (ns) Human health (CTUnoncancer and cancer) Ozone depletion (kg CFC-11 eq)	TRACI 2.1 (USA)	ecoinvent Literature	Soymilk, cowmilk, soya meatballs, and beef sausage	Raw	Nutrient quantity	USDA
Green et al. (2023)	Global	Food groups representative of a national food supply	1 Kg food 100 Kcal NRF9 NRF9.3 NBC	Cradle-to-Retail	Climate change (Kg CO2eq) WU (L) LU (m2) Eutrophication (kg PO4 3−eq) Acidification (kg SO2 eq)	EF (Europe)	Literature	144 most consumed foods globally	Ready to Eat	NRF9 NRF9.3 NBC FSI	USDA
Ceballos-Santos et al. (2024).	Europe	Fish and Seafood from European Atlantic countries	1 Kg food	Cradle-to-Farm Cradle-to-Industry	Climate change (Kg CO2eq) WU (ns) Freshwater eutrophication (ns) Marine eutrophication (µPt) Energy footprint (MJ)	GWP 100 year IPCC 2021 AWARE ReCiPe 2008 Cumulative Energy Demand	Primary Data Literature	Fish and Seafood from European Atlantic countries	Not specified	NRF12.2	Spanish Food Composition Tables

Abbreviations: DALYs (Disability-Adjusted Life Years); FNI (Finnish Nutrient Index for protein sources); FSI (mentioned in Green et al. 2023); FU (Functional Unit); HENI (Health Nutritional Index); LU (Land Use); MAR (Mean Adequacy Ratio); MER (Mean Excess Ratio); NBC (Nutrient Balance Concept); NDS (Nutrient Density Score); NRD (Nutrient Rich Diet Index); NRF (Nutrient Rich Food Index); PQI (Protein Quality Index); ns (not specified); SAIN:LIM (Score of Nutritional Adequacy of Individual Foods (SAIN); Score of Nutrients to be Limited (LIM)); SED (Solid Energy Density); SNRF (Sustainable Nutrient Rich Food Index); WU (Water Use); and YLL (Years of Life Lost). Characterization methods and data sources are reported as originally described in each study meet nutritional recommendations while reducing environmental pressures. Third, a subset of studies ($n=11$; 48%) used the assessment to develop, test, or refine methodological approaches, such as nutrient-adjusted FUs, integrated sustainability scores, nutrient profiling algorithms, health-based nutritional indicators, or combined environmental–nutritional indexes. Across these framings, most studies sought to support interpretation or decision-making related to food choices, dietary changes, or sustainable diet transitions, rather than presenting nutritional and environmental results as fully independent parallel assessments.

3.2 Environmental dimension

3.2.1 FUs and system boundaries

Four main types of FU formulations were identified (Table 1), with a clearly uneven distribution. Mass-based FUs overwhelmingly predominated ($n=19$, 83%), most commonly expressed as "1 kg of food" ($n=12$; 52%) or "100 g of food" ($n=6$; 26%), with only one study using volume-based units (1 L). Diet-related FUs were the second most frequent category, used in nine cases overall (39%), including "daily diet" ($n=7$; 30%), "per serving" ($n=2$; 9%), and "yearly diet" ($n=1$; 4%). By contrast, energy-based FUs were relatively uncommon, appearing in four instances (17%), and included formulations such as 100 kcal ($n=2$; 9%), 1000 kcal ($n=1$; 4%), and 2000 kcal ($n=1$; 4%). Nutrient-based FUs were similarly limited in frequency but more heterogeneous in nature. These included single-nutrient metrics, such as grams of protein ($n=2$; 9%) or digestible protein ($n=1$; 4%), as well as composite or quality-adjusted indicators. Three articles (13%) used such aggregated nutrient indicators (i.e. nutrient scores), including the Nutrient Rich Foods (NRF) family and related indexes (e.g., NRF scores applied at diet level as Nutrient Rich Diet (NRD) indexes), as well as the Finnish Nutrient Index for protein sources (FNIprot7) and the Nutrient Balance Concept (NBC). A clear temporal pattern emerged across studies. Earlier publications relied almost exclusively on mass- and, to a lesser extent, diet-based FUs, whereas studies published from around 2017 onwards increasingly incorporated energy- and nutrient-based formulations, including measures of protein quality and composite nutrient scores.

The review of system boundaries revealed substantial heterogeneity across the 23 included studies (Table 1), with six distinct boundary formulations identified. The most frequently applied boundary was cradle-to-grave ($n=7$; 30%), followed by cradle-to-consumption ($n=5$; 22%). Together, these consumer-oriented system boundaries accounted for over half of the studies ($n=12$; 52%), indicating a relatively strong emphasis on capturing environmental impacts up to the point of consumption. In parallel, truncated system boundaries were also widely used. Cradle-to-industry gate was applied in five studies (22%), including one originally labelled as "cradle-to-gate", while cradle-to-farm gate boundaries were identified in four studies (17%), including one reported as "cradle-to-farm". Less frequent formulations included cradle-to-retail ($n=2$; 9%) and cradle-to-distribution ($n=2$; 9%), while one study (4%) did not explicitly specify its system boundary. From a temporal perspective, earlier studies (2014–2016) predominantly relied on more comprehensive, consumer-oriented boundaries, particularly in diet-level assessments. From around 2017 onwards, a broader range of system boundary definitions emerged, with an increasing use of truncated approaches (e.g., cradle-to-farm or industry gate), especially in product-level analyses. However, unlike the trend observed for functional units, no clear convergence toward a single preferred system boundary is apparent, and both comprehensive and truncated approaches continue to coexist in recent studies.

3.2.2 Life cycle inventory and data sources

Across the reviewed studies, substantial variability was observed in the procedures employed to construct the LCI (Table 1). In some cases, the source of the data was not explicitly discussed in the main text of the study and had to be traced through cited references or supplementary materials. Several studies ($n=10$; 44%) included the use of databases that gather specific food products LCIs from different countries, but a minority of those studies relied exclusively on them (ecoinvent $n=1$; 4%, Agri-footprint $n=1$; 4%, RISE Food Climate Database $n=1$; 4%). The other studies used such databases in combination with others (ecoinvent $n=6$; 26%, Agri-footprint $n=1$; 4%). Environmental data from some studies were reportedly compiled by environmental consulting firms ($n=4$; 17%), which in most cases ($n=3$; 13%) involved integrating data from different sources. A significant number of studies ($n=12$; 52%) relied on a mix of literature-based estimates sometimes with other sources including databases, and digital tools. Two studies were entirely based on data from a previously published systematic review, and one study performed its own review. Additionally, one study used interviews and surveys as the primary source of environmental impact data. A temporal pattern was also apparent in the type of life cycle inventory data and environmental data sources used across studies, although this trend was less pronounced than for functional units. Earlier studies included in this review relied mainly on secondary data sources, particularly LCA databases such as ecoinvent and published literature, often with limited detail on inventory construction or data adaptation. From around 2017 onwards, the range of data sources appears more diverse and detailed described, with increasing use of food-related LCA databases, national or institutional datasets, supply-chain-specific data, and combinations of multiple sources.

Explicit consideration of geographical origin and trade dynamics was rare among the reviewed literature ($n=6$; 26%). While these few studies specified whether environmental impact data accounted for imported products, the majority lacked transparent documentation regarding the treatment of trade. Consequently, the extent to which import-related particularities were integrated into the assessment of consumed foods remains largely indeterminate.

3.2.3 Environmental impact categories and characterization methods

In terms of environmental impact categories, most studies ($n=19$; 82%) assessed only one to four environmental impacts, with only four studies reporting the results from a broader multicriteria environmental assessment encompassing a more complete overview. Climate change was the only category reported by all 23 studies. LU was assessed in ten studies (43%), followed by water related impact categories in seven studies (30%), eutrophication (fresh and marine water) in six studies (26%), acidification (air, terrestrial, or freshwater) in five studies (22%), energy or fossil energy use in four studies (17%), and ecotoxicity in four studies (17%). Less frequently used indicators included human toxicity ($n=2$; 8%), ozone depletion ($n=2$; 8%), and biodiversity loss ($n=1$; 4%), among others (Table 1). The selection of environmental impact categories and characterization methods also appeared to broaden over time, although not following a clear cut-off point. Earlier studies often focused on climate change alone or combined it with a small number of additional indicators, such as acidification, eutrophication, land use, or resource consumption. In contrast, later studies more frequently included broader multi-impact profiles covering categories such as water use, land use, eutrophication, acidification, ecotoxicity, fossil energy use, biodiversity-related indicators, and human health-related impacts. This broadening was accompanied by greater use of explicit characterization methods, including IPCC-based approaches for climate change and multi-impact frameworks. However, this trend was heterogeneous, as some recent studies still relied on a limited number of indicators. Overall, this pattern indicates that climate change was the only environmental dimension consistently represented across the reviewed studies, whereas other impact categories were included more selectively.

The reviewed studies employed a broad range of characterization methods to assess environmental impacts, with notable variability in the degree of methodological transparency and alignment with established LCA frameworks (Table 1). Notably, eight studies (35%) did not specify any characterization method, completely relying instead on secondary sources such literature-derived values, without always standardizing methodological aspects for consistency. Only twelve studies explicitly stated in the actual publication the underlying LCA characterization method (ReCiPe 2008 ($n=2$; 8%), TRACI 2.1 ($n=1$; 4%), IMPACT World+ ($n=1$; 4%), and CML ($n=1$; 4%)), individual models ($n=2$; 8%) or set of models used ($n=7$; 30%, including 2 of them which were combined with characterization methods). Regarding publications that stated the use of LCA characterization methods, all methods employed include a wide range of midpoint, and in some cases endpoint results. Nevertheless, in most cases, only a subset of these indicators was reported in the final manuscripts, often with no justification of the selection of impact categories shown.

The most frequently mentioned indicator for quantifying the impact of climate change was the Global Warming Potential (GWP) 100-year, based on Inter Governmental Panel of Climate Change (IPCC) guidelines. Only two studies explicitly stated the reference year. LU was most commonly reported as an inventory indicator ($n=5$; 22%), calculated simply as the cumulative occupied area (m^2 year) without any characterization step, although it was often expressed in surface-related units (e.g., m^2 or hectare), without indicating the temporal dimension of this measure. In some cases ($n=3$; 13%) studies indicated the use of characterization models to assess land use, such as IMPACT World+ ($n=1$), ReCiPe ($n=1$) or Environmental Footprint ($n=1$; 4%). Water related impact category was the category assessed with the more diverse approaches, including the available water remaining (AWARE) indicator, Water Footprint Network or water stress coefficients, as well as just reporting the inventory or amount of water consumed. Less frequently, studies focused on environmental impact assessment in energy-related indicators such as Cumulative Energy Demand or Cumulative Exergy Extraction for Natural Environment (CEENE) (Table 1).

3.3 Nutritional assessment dimension

3.3.1 Nutritional metrics

Across the 23 studies included in this review, a total of 25 distinct nutritional or health indicators were identified, reflecting substantial methodological diversity in how nutrition- or health-related aspects are incorporated into environmental assessments (Table 1). These indicators can be grouped into four main categories: composite nutrient-based indicators, single-nutrient indicators, health-outcome-based indicators, and energy-based metrics. This classification highlights that nutritional indicators differ not only in their level of aggregation—from single nutrients to composite scores—but also in their conceptual scope, ranging from nutrient composition to estimated health outcomes.

Composite nutrient-based indicators were the most frequently used category (n = 11; 48%), combining multiple nutrients into a single score to capture the overall nutritional profile of foods or diets. These included the NRF family and related indices the French SAIN: LIM, the PANDiet index, the Nutrient Density Score (NDS), the NBC, FSI, FNIprot7, FNIprot7.2, as well as adequacy–excess metrics such as the Mean Adequacy Ratio (MAR) and the Mean Excess Ratio (MER). Single-nutrient indicators were the second most frequently applied type (n = 7; 30%), representing assessments based on individual nutrients—such as proteins, amino acids, or selected macro- and micronutrients—without aggregation into composite indices. Health-outcome-based indicators were less frequent (n = 4; 17%), but represented a distinct approach by capturing downstream health impacts associated with dietary exposure. These included Years of Life Lost (YLL), Disability-Adjusted Life Years (DALYs), the Health and Environmental Nutritional Index (HENI), and reported health risks. Lastly, energy-based metrics were the least commonly used (n = 2; 9%), typically relying on energy intake (kcal) or the Solid Energy Density score (SED, kcal/g) to represent the energetic contribution of foods. The nutritional and health metrics used across studies also became more diverse over time. Earlier studies primarily relied on nutrient profiling or diet quality indicators, usually based on national food composition databases. Later studies increasingly incorporated a broader range of approaches, including nutrient quantity, protein-related indicators, composite nutrient scores, and health risk estimates.

3.3.2 Food composition data and preparation

The most frequently used food composition database was USDA (United States, n = 9; 39%), followed by European food composition databases which included CIQUAL (France, n = 3: 13%), NEVO (Netherlands, n = 2; 8%), and Swedish Food Composition Database (Sweden, n = 2; 8%), as well as others from outside of Europe such as IFCT (India, n = 2, 8%). Additional sources with lower appearances included BEDCA (Spain, n = 1; 4%), FINELI (Finland, n = 1), UK Food Composition Database (United Kingdom, n = 1, 4%), and NUBEL (Belgium, n = 1; 4%). A few studies (n = 5; 22%) combined multiple databases (e.g., CIQUAL and USDA, n = 1; 4%; IFTC and USDA, n = 1; 4%, or multiple national food composition tables, n = 3; 13%).

Regarding food preparation, ten studies (43%) explicitly used ready-to-eat (cooked or raw without inedible parts, depending on food products) food values in their nutritional assessments, indicating an emphasis on realistic consumption scenarios that mirror actual dietary exposure. Three studies (13%) applied a combination of raw and cooked data, typically when assessing diverse food items or composite meals. Two studies used exclusively raw food composition data, limiting their representativeness with respect to final nutrient intake. In eight studies, the treatment of food preparation was not specified.

3.4 Methodological alignment between environmental and nutritional assessments, and their contextual application

Figure 2 illustrates the alignment between the study goal and scope with the environmental (first block of the figure) and nutritional (second block) assessments, as well as the consistency between these two dimensions (third block). Alignment was interpreted according to the operational criteria described in Sect. 2.2, with green indicating full alignment, yellow indicating partial alignment, and red indicating lack of alignment or insufficient information to assess compatibility. The study-level rationale for each color attribution in Fig. 2 is detailed in Online Resource 3.

3.4.1 Alignment between study aim and scope, and environmental assessment

Geographic alignment between the study goal and scope and the environmental assessment was evaluated based on the LCIs used (first column of Fig. 2) and the characterization methods applied (second column of Fig. 2). The most common pattern was partial geographic compatibility, observed in nine studies (39%), often due to the use of multi-country inventories or secondary sources with unclear geographical granularity. Eight studies (35%) relied on inventories or LCA datasets representative of the study's national or regional context; however, it was not always clear whether international trade was considered in dataset selection. Four studies (17%) did not provide sufficient detail to assess geographic compatibility, while two studies (9%) used datasets clearly misaligned with the target context.

The characterization methods applied across studies varied substantially, further affecting geographic comparability (second column of Fig. 2). The most frequent situation was the lack of specification of the characterization method or model (n = 9, 39%), including three studies in which values were assigned by a consulting firm. Within this group, several studies assessed only climate change (n = 7, 30%), where the use of global characterization factors reduces regional bias. A smaller number of studies applied methods that were only partially aligned with the study context (n = 6, 26%), such as non-regionalized water footprinting approaches or

Fig. 2 Alignment between environmental and nutritional/health dimensions, and their context across reviewed studies. Color reflects the degree of methodological alignment between dimensions based on the presence of consistent data sources, characterization methods, system boundaries, and aims. Green indicates full alignment, yellow partial alignment, and red absence of alignment or insufficient data. Study-level justification for the color choice can be found in Online Resource 3

global exergy indicators. Only a limited number of studies ($n=5$, 22%) explicitly used standardized frameworks relevant to the study context, including region-specific methods such as CML (Netherlands, $n=1$; 4%) and TRACI (USA, $n=1$; 4%), as well as globally applicable methods such as Impact World+ ($n=1$; 4%) and ReCiPe ($n=2$; 9%), applied in contexts consistent with their intended use.

Alignment was also assessed in terms of coherence between the stated study aims and the system boundaries adopted in the environmental assessment (third column of Fig. 2). Full alignment was the most common outcome, observed in 14 studies (61%), where the life-cycle stages included in the LCA corresponded to the analytical objective. For example, studies aiming to assess the sustainability of diets or food consumption patterns typically extended system boundaries to the point of consumption. Partial alignment was identified in five studies (22%), in which the stated aim focused on consumer-level or dietary recommendations, while environmental impacts were restricted to upstream stages, thereby omitting downstream processes relevant for interpretation in dietary or public health contexts.

Overall, only three studies (13%) achieved full alignment between the study goal and scope and the environmental assessment across all three variables considered (LCI database, characterization method, and coherence between system boundaries and study aim).

3.4.2 Alignment between study aim and scope, and nutritional assessment

Geographic alignment between the study scope and the nutritional assessment (fourth column of Fig. 2) was most commonly achieved through the use of country-specific nutrient composition databases, observed in 15 of the 23 studies (65%). This suggests a systematic effort to contextualize nutrient estimates within the study setting. Partial alignment was identified in six studies (26%), typically reflecting the combination of international data sources with region-specific adjustments. Only two studies (9%) relied on clearly non-representative databases; for example, one study conducted in a French context used the USDA food composition database despite the availability of a national reference database (CIQUAL).

Alignment between the food preparation stage considered in the nutritional assessment and the study aim was also assessed (fifth column of Fig. 2). Full alignment was observed in 15 studies (65%), where nutritional assessments referred to foods as consumed, consistent with objectives related to dietary patterns, meal composition, or population health. In contrast, no alignment was identified in the remaining studies (35%), where the treatment of food preparation stages did not correspond to the stated analytical objectives.

Overall, 10 studies (43%) achieved full alignment between the study goal and scope and the nutritional assessment across both variables considered (nutrient database representativeness and coherence between study aim and food preparation stage).

3.4.3 Alignment between the environmental and nutrition dimensions

Consistency between the environmental and nutritional dimensions was assessed based on the alignment of scope (sixth column of Fig. 2), the correspondence between system boundaries and food preparation stages (seventh column of Fig. 2), and the geographical consistency between the data sources used in both dimensions and the study context (eighth column of Fig. 2).

Regarding scope, full alignment was the most common outcome, observed in 15 studies (65%), where the same foods or food groups were assessed in both dimensions, enabling direct environmental–nutritional comparisons. In contrast, eight studies (35%) showed divergent scopes, typically due to the combination of aggregated dietary patterns in one dimension and product-specific assessments in the other, or the exclusion of certain food categories from either the environmental or nutritional analysis. For example, one study evaluated the nutritional quality of three Swedish dietary patterns but estimated environmental impacts using only six representative foods included in those diets.

In terms of consistency between system boundaries and food preparation stages, full alignment was less common, observed in eight studies (35%). These cases evaluated foods at the ready-to-eat stage in both dimensions, with environmental system boundaries extending through processing and cooking, and nutritional data reflecting foods as consumed. Partial alignment was identified in three studies (13%), typically when nutritional values were derived from a combination of raw and cooked foods while environmental system boundaries did not fully extend to the point of consumption, resulting in only partial overlap between the stages represented.

Regarding geographical consistency, full alignment was observed in four studies (17%). In these cases, both the environmental and nutritional data sources were geographically consistent with the study context, supporting a more coherent comparison between the two dimensions. Partial alignment was the most frequent outcome, identified in 16 studies (70%). This was generally due to one dimension being geographically aligned with the study context while the other relied on broader, international, or non-specific data sources, such as generic LCA databases, or literature-derived estimates. No geographical alignment was observed in three studies (13%), reflecting clear mismatches between the geographical context of the study and the data sources used for the environmental and nutritional assessment.

Overall, only one study (4%) showed full alignment across the three variables considered for the assessment of consistency between the environmental and nutritional dimensions: scope, system boundaries and preparation stage, and geographical context. This indicates that, although several studies achieved alignment for individual variables, simultaneous consistency across product scope, methodological boundaries, preparation stage, and geographical representativeness was rarely achieved.

4 Discussion

This review revealed a highly heterogeneous methodological landscape in n-LCA studies, with substantial variation in the approaches used to address environmental and nutritional assessments, and particularly how they integrate both dimensions when assessing the impacts of food products or dietary patterns. Differences were observed in the choice of FUs, system boundaries, environmental impact categories, nutritional metrics, and geographic context. While such diversity reflects the experimental and evolving nature of n-LCAs, the most critical issue lies in the methodological consistency and transparency of each individual dimension. In many cases, even when dimensions are well defined individually, their integration remains unclear, undermining the interpretability and relevance of the results. The findings of this review suggest that future methodological developments in n-LCA should prioritize three areas: (i) improving the geographical representativeness of environmental and nutritional datasets and addressing uncertainty; (ii) ensuring transparency and consistency across environmental and nutritional components; (iii) strengthening the incorporation of nutrition- and health-related dimensions. Therefore, future research should ensure methodological adequacy and alignment not only within each dimension but also across them, thereby enabling integrated assessments to more accurately reflect the complexity and interdependence of food-related health, nutrition, and environmental outcomes. This would enhance comparability, reduce uncertainty, and increase the policy relevance of current n-LCA evidence.

4.1 Inaccurate environmental impact data

The reliability of environmental impact assessments in current n-LCA studies is frequently compromised by inconsistencies or insufficient reporting in data sources, LCI construction, and impact characterization methods. A considerable number of studies rely wholly or partially on secondary LCI data, or even pre-characterized environmental impact values sourced from diverse databases and literature. While this may facilitate the integration of environmental information into nutrition-oriented assessments, this often reflects production systems that are misaligned with the geographical or technological context of the analysis (Wu and Wang 2022). This disconnection introduces assumptions that may not accurately represent local agricultural practices, supply chains, or consumption behaviors, thereby undermining the validity and relevance of the results. Certainly, the environmental impact of a specific product can vary substantially depending on regional factors, production techniques, and resources availability (Poore and Nemecek 2018). Even when reputable databases such as Agri-footprint or ecoinvent, which provide datasets representing different regions and agricultural production practices, are used, few studies explicitly describe the specific datasets selected (e.g., GLO, RER, or country-specific datasets), if imports were considered, or whether methodological harmonization has been undertaken when combining environmental data from multiple sources. Together, the limited transparency regarding dataset selection, the inconsistent treatment of imports, and the lack of harmonization across environmental data sources can introduce substantial uncertainty and reduce comparability across studies. These issues may lead to distortions in environmental impact estimates, particularly when differences in allocation procedures, system boundaries, production conditions, or trade assumptions are not adequately addressed. The limited traceability of the specific environmental datasets used in n-LCA studies therefore emerged as a key methodological concern in this review. Future n-LCA studies relying on secondary environmental data should clearly report how environmental datasets are selected, harmonized, and adapted to the context of analysis, including the treatment of imported goods where relevant.

A further limitation lies in the omission or vague reporting of impact characterization methods. LU has been identified in this review as a particularly illustrative example. In many reviewed studies, LU was assessed merely as inventory data (e.g., m^2 of land occupied), without translating this into actual environmental impacts. Although such inventory-based indicators can be informative, useful for comparisons of scenarios, and complementary to the LU impact category, they should not be interpreted as a complete impact assessment. Furthermore, substantial inconsistency was observed in the units used. While land occupation should technically be reported in area x time units (e.g., m^2 year), many studies reported only area, thus omitting the temporal dimension. This omission reflects a frequent confusion in literature, where land occupation and land transformation are not always distinguished (land transformation should be expressed purely in surface terms, while land occupation should also include the temporal frame).

For categories for which regionalized characterization is available, such as acidification or terrestrial eutrophication (Seppälä et al. 2006; Posch et al. 2008), there was a lack of clear reporting regarding whether global or regionalized characterization factors were applied, an issue that can lead to different conclusions (Ruiz-Colmenero et al. 2024). Besides the influence of pedoclimatic conditions or ecosystem sensitivity to impact might be partially considered because of consequent changes in yields, this lack of clarity concerning characterization choices suggests a limited awareness of their influence on the validity and comparability of results. Certainly, the selection of characterization methods itself is a source of uncertainty. In this sense, when it is considered that the characterization method selection can affect findings, sensitivity analyses on characterization methods should be performed, as recommended by ISO 14044 (2006b). However, this practice was almost entirely absent from the included publications, even among the few studies that did report the characterization method employed.

Overall, characterization was overwhelmingly dominated by climate change, as all reviewed studies reported climate change impacts and most relied on the IPCC 100-year GWP. While this likely reflects both the robustness of climate metrics and their prominence within sustainability research, it may also be influenced by the greater availability of climate-related data in open-access databases and scientific publications, which allows these impacts to be estimated more easily, often without the need for specialized LCA software. This may partly explain their widespread use in n-LCA studies, where researchers do not always have extensive expertise in LCA. In contrast, the inclusion of other environmental impact categories remained sporadic. As highlighted in this review, even the application of characterization frameworks encompassing a broad range of environmental indicators did not necessarily result in comprehensive multicriteria assessments, as studies frequently reported only a limited subset of the available impact categories. This contrasts with the nutritional and health dimensions, which often encompass a wider range of nutrients, dietary components, or health outcomes. Such selective reporting risks obscuring important trade-offs among environmental pressures (Nemecek et al. 2016), potentially distorting the perceived relationship between health and environmental sustainability by overlooking impacts in other environmental domains. Indeed, reliance on climate-related indicators alone may mask burdens associated with water scarcity, land degradation, biodiversity loss, and nutrient pollution, all of which are highly relevant and context dependent. Ultimately, such selective reporting reduces the comprehensiveness of n-LCA findings and limits their usefulness for informing holistic policy development and food system transformation. Regardless of the reasons behind such selectivity—which may include space constraints, prioritization choices, or considerations related to the study goal and scope—greater transparency would strengthen future research. In particular, authors should explicitly justify the selection of impact categories and, where feasible, provide complete characterization results as supplementary material.

4.2 Incorporation of nutritional and health effects in LCAs

This review highlights that the nutritional dimension is frequently incorporated into n-LCAs through the definition of the FU. While mass- and volume-based FUs, rooted in conventional product-level LCA, remain predominant, an increasing number of studies are adopting alternative formulations. Energy-based and nutrient-based FUs have gained traction as they more accurately reflect the functional purpose of food consumption, which is providing energy and nourishing. Moreover, some studies have advanced this approach in the latest years by integrating composite nutritional indicators, such as nutrient density scores, directly into FU definitions (Röös et al. 2015; Saarinen et al. 2017; Green et al. 2023; Fresán et al. 2026). This diversification signals a methodological shift toward functionally meaningful FUs that better align nutritional and environmental perspectives. Despite this progress, there remains an ongoing debate regarding the most appropriate nutritional index to use as FU in n-LCA and how to solve inconsistencies (McAuliffe et al. 2020; Reguant-Closa et al. 2024). Given the diversity of n-LCA applications, it is a challenge to generalize a FU that fits the large variety of n-LCA studies scopes. It is possible that no single indicator is universally applicable across all n-LCA studies; rather, the choice of nutrient-based FU should be guided by the specific goal and scope of the assessment, as this is the case with traditional environmental LCA studies (ISO 14040 2006a). Crucially, the rationale for selecting a particular index must be clearly articulated, as this decision can substantially influence the outcomes and interpretations of the study. Conducting a sensitivity analysis (only applied in 22% of the studies reviewed) would be recommended to evaluate whether the conclusions hold when alternative indicators are applied (Shippey et al. 2025). It is important to highlight, however, that while the integration of nutritional indicators into the FU represents a significant advancement in n-LCA methodology, it does not mean that mass-based FUs are irrelevant. Although mass-based functional units are poorly suited to capture the dietary role of foods (Saarinen et al. 2017; Sonesson et al. 2017), they may be appropriate for comparing alternative production or management scenarios of the same food product, where nutritional composition is not expected to differ substantially. Importantly, the use of mass-based FUs also enhances comparability across studies, as results expressed per unit of mass can be more readily aligned and contrasted. In addition, mass-based reporting provides a flexible basis on which results can be subsequently adapted or recalculated to alternative functional units, including energy- or nutrient-based metrics, depending on the study objective.

While a few environmental assessments collected and analyzed primary data, all nutritional assessments relied on secondary data. This is an important methodological consideration, as the accuracy of nutritional assessments depends not only on the availability of food composition data but also on how well those data represent the foods and dietary context under study. Although several studies sought to improve contextual relevance by using national food composition tables, this review highlights that many countries still lack food composition databases or do not have sufficiently comprehensive resources. Reliance on datasets reflecting foreign food products can lead to misrepresentation of the nutritional profiles of assessed items, particularly in the case of multi-ingredient foods, whose formulations often vary substantially across regions (Vin et al. 2020). Going one step further, when assessing diets or foods consumed in a given region, the issue extends beyond whether a database is national to how accurately it reflects the actual food supply, which may include a substantial proportion of imported products. As stated in their methodological reports, most national food composition databases aim to be representative of foods available on, or commonly consumed within, the domestic market, including imported foods. However, they do not always capture compositional variability associated with production region, crop variety, agricultural practices, or post-harvest conditions. Accurate data reflecting these characteristics are essential, as they can substantially influence nutrient composition (Bhardwaj et al. 2024). Accounting for preparation effects is also relevant, as cooking and other household practices can substantially affect nutrient retention and composition (Goluch et al. 2025; Lisciani et al. 2025). Furthermore, the inclusion of data for ready-to-eat foods is important, given that industrial processing, storage, and preparation can significantly alter nutritional composition throughout the food system (Singh et al. 2023). Broadening nutritional composition data to better reflect real consumption conditions would improve the validity of nutritional assessments and support more contextually relevant n-LCA evaluations.

Moreover, it is noteworthy that only a limited number of studies have addressed the healthiness of foods or diets, focusing instead on nutrient composition or quality. There is a pressing need to incorporate health outcomes, such as impacts on mortality, morbidity, or quality of life, into sustainability assessments. Nutrient composition alone, even when adjusted for bioavailability, does not necessarily align with health effects, and overlooking this distinction may lead to misleading conclusions (Delgado et al. 2021; Cardinaals et al. 2024; Fresán et al. 2026). Although this research line in n-LCA is still in its infancy and current data and methods involve considerable uncertainty specially for individual food products (Stylianou et al. 2021), integrating epidemiological evidence into environmental nutrition research remains essential to ensure that sustainability metrics are aligned with public health goals (Fresán et al. 2026). Addressing these uncertainties should be a priority for future methodological development (Scherer et al. 2024).

4.3 Misalignments among dimensions

Beyond the dimension-specific issues discussed above that affect the adequacy of each assessment (e.g., geographic consistency), methodological misalignments may arise when environmental and nutritional assessments are integrated within the same n-LCA study. These include inconsistencies in product scope, system boundaries that can compromise the coherence of the overall assessment.

Regarding product scope, many studies aggregate environmental impacts at the food group level, whereas nutritional analyses distinguish individual food items. For instance, like Drewnowski (2024) pointed out, while nutritional differences among meats such as beef, pork, and poultry are often captured, it is possible to find diet environmental assessments that combine these into a single category (e.g., "meat" including all animal based meat), or separating "chicken" and "red meat" grouping pork with ruminants, thereby obscuring substantial variation in their respective environmental impacts (Eshel et al. 2014; Clark et al. 2019). This aggregation can lead to either underestimation or overestimation of results depending on which specific meats are represented (Poore and Nemecek 2018). A comparable disconnection arises in dietary assessments where nutritional composition and health effects are evaluated at the whole-diet level, yet environmental impacts are derived from a limited subset of foods, typically unprocessed or raw items (González et al. 2020). This inconsistency is particularly problematic for foods where health and environmental performances diverge. Certain plant-based foods, for example industrial pastries, may exhibit low environmental burdens but have limited nutritional value or potential adverse health effects; or in the other way around, healthy foods such as some fish species can have significant environmental impacts (Berardy et al. 2025). If such foods are included in health assessments but excluded from environmental evaluations, the analysis may misleadingly suggest that healthiness and environmental sustainability are inherently aligned, an assumption that does not always hold true (Fresán et al. 2020; Peruvemba et al. 2025).

System boundary mismatches may be also problematic. Many studies rely on environmental data truncated at the farm-gate or industry-gate level, whereas nutritional assessments are anchored at the point of consumption. This inconsistency systematically underestimates environmental burdens relative to nutritional outcomes, introducing bias into cross-dimensional comparisons. Where feasible, n-LCA should extend their boundaries to the consumption stage to ensure methodological consistency and comparability across both environmental and nutritional dimensions. It should be noticed, however, that primary production is the dominant contributor to food-related environmental impacts (Poore and Nemecek 2018; Crippa et al. 2021). Therefore, the exclusion of downstream stages is not expected to substantially alter impact estimates. Additionally, if the goal is comparing food products with similar downstream processes, main conclusions would not change by the inclusion of those stages. Nevertheless, some studies have demonstrated that variations in system boundary definitions can significantly influence environmental results for specific food categories (Dénos et al. 2024), particularly for highly processed plant-based products (Mejia et al. 2019) and when using energy-consumptive storage and cooking methods (Frankowska et al. 2020).

4.4 Priorities for future n-LCA development

Drawing on the findings of this review, several priorities were identified to guide the future development of n-LCA studies:

4.4.1 Data harmonization and methodological consistency

One of the main priorities emerging from this review is the development of harmonized and interoperable data infrastructures that integrate environmental and nutritional dimensions. Developing country-specific LCI datasets for foods and publicly available, pre-characterized environmental databases aligned with national food composition tables would substantially reduce many of the geographical and methodological inconsistencies identified in this review (Furrer et al. 2024). Such infrastructures should incorporate region-specific agricultural practices, account for food imports, and include inventories covering multiple stages of the food system, thereby facilitating their application in dietary assessments. Achieving this goal will require coordinated efforts among nutritional scientists, LCA practitioners, database developers, public institutions, and industry stakeholders. Public initiatives can play a central role in ensuring transparency, standardization, and accessibility, while private initiatives may contribute higher-resolution inventories and technical expertise. Developing and maintaining such databases requires substantial resources and long-term institutional commitment.

Until such infrastructures become widely available, most assessments will inevitably keep on relying on proxy datasets and assumptions. Rather than representing a methodological flaw, this reflects a structural reality of n-LCA practice, given the persistent data gaps across many food–country combinations. In this context, understanding how proxy selection and characterization methods influence results is essential for making informed methodological choices. Whether adopting data for the same food from a different geographical region or using taxonomically similar food from the same country, suitability should be empirically evaluated rather than assumed. From the environmental perspective, ongoing harmonization initiatives such as the European Commission's Environmental Footprint (EF) framework and the Global Guidance for LCIA Indicators and Methods (GLAM), although not specifically designed for n-LCA applications, provide useful examples of how methodological consensus can be developed through coordinated efforts among researchers, public institutions, database developers, industry stakeholders, and other actors. For nutritional proxies, data selection should prioritize regions with comparable regulatory and industrial frameworks. Differences in labelling requirements, food fortification policies, and processing practices can substantially affect nutrient composition and, consequently, the nutritional assessment within n-LCAs. When direct alignment is not feasible, researchers should apply transparent and justified adjustments —particularly for nutrients such as sodium, added sugars, and fortified micronutrients— and evaluate their influence through sensitivity analyses to minimize the risk of over- or underestimating nutritional quality.

The suitability of proxy datasets should be evaluated whenever possible through empirical evidence, sensitivity analyses, and scenario testing. These approaches can help quantify the influence of alternative assumptions on study conclusions and strengthen confidence in results derived from secondary data. Overall, the focus should be on making uncertainty transparent, quantifiable, and manageable.

4.4.2 Reporting standards

Another priority emerging from this review is the improvement of reporting practices and methodological transparency. A major concern identified across the reviewed studies is the limited traceability of the data used, particularly for the environmental dimension. Although databases and literature sources are often cited, the specific datasets, proxies, geographical assumptions, and other modelling choices are frequently insufficiently documented, making it difficult to assess consistency between environmental and nutritional dimensions and limiting reproducibility. ISO 14044 requires the reporting of data limitations and data-quality considerations, including geographical representativeness. Building on these principles, the establishment of minimum reporting standards for n-LCA studies would substantially improve transparency, reproducibility, and credibility. Greater transparency would not only facilitate the replication and updating of studies, but also enable readers to better assess the validity, transferability, and uncertainty of the findings. Future studies should therefore provide sufficient information to allow the evaluation and replication of methodological choices, including the environmental and nutritional datasets used, their geographical origin, database versions, characterization methods, proxy selection, cooking and processing assumptions, and any use of non-representative data sources. When space is limited, this information should be made available in supplementary materials or at least in a repository clearly indicated in the publication or report.

4.4.3 From multicriteria to holistic assessment

From a forward-looking perspective, future n-LCA research should move beyond nutrient-based evaluations by incorporating health-based approaches that better capture the effects of foods and dietary patterns on human health (Cardinaals et al. 2024; Fresán et al. 2026). While nutrient composition remains an essential component of food assessment, it does not necessarily reflect the health outcomes associated with food consumption. Integrating health-related metrics would increase the relevance of n-LCA studies for public health and policy applications while providing a more comprehensive evaluation of food sustainability. Further methodological development is needed to strengthen the incorporation of epidemiological evidence into sustainability assessments while appropriately addressing the associated uncertainties. A more holistic perspective also requires broadening the environmental dimension beyond climate change. The systematic application of environmental assessment frameworks covering multiple impact categories should be encouraged to better capture environmental trade-offs and avoid an excessive focus on greenhouse gas emissions alone. Finally, achieving truly integrated assessments will require closer collaboration between LCA practitioners and nutrition experts to ensure that environmental, nutritional, and health dimensions are jointly considered from study design to interpretation, rather than being combined only at the final stage of the assessment.

4.5 Implications of methodological shortcomings and misalignments identified in this study

The shortcomings and misalignments identified in this study may have important consequences for the interpretation and comparability of findings across studies, as well as for their use in decision-support contexts. As Green et al. (2023) noted, methodological robustness in n-LCAs is essential not only for comparability but also for credibility in policy processes. Integrated assessments are increasingly cited in debates on sustainable dietary guidelines and food policy; however, when nutritional and environmental dimensions are not comprehensively assessed and coherently aligned, the resulting evidence may be fragmented or misleading. Reliance on inconsistent data sources, system boundaries, geographical contexts, or a limited set of environmental indicators may distort health–environment trade-offs and lead to incomplete or biased conclusions. This is particularly relevant in the context of dietary transitions, where n-LCAs may inform dietary guidelines, eco-labelling schemes, procurement criteria, and broader food policy recommendations. In such contexts, methodological limitations are not merely technical issues; they can influence how evidence is translated into decisions, potentially overstating synergies or obscuring important trade-offs between health and environmental sustainability.

Importantly, not all the inconsistencies identified in this review necessarily compromise the validity of n-LCA results. Their relevance depends on the goal and scope of the assessment, and it should be acknowledged that nutritional and environmental dimensions do not always require identical methodological approaches. Understanding the implications of these inconsistencies is therefore essential for the appropriate interpretation and use of findings. While geographical consistency, environmental categories targeted, and scope alignment appear a priori to be among the methodological aspects most likely to influence the interpretation of environmental–nutritional trade-offs, the importance of these and other choices, such as system boundaries, FUs, or the use of proxy data, remains highly context-dependent. Consequently, not all forms of misalignment should be expected to affect study conclusions to the same extent.

For example, geographical inconsistencies are most likely to affect results when environmental impacts or nutritional characteristics are strongly shaped by local production conditions, supply chains, food formulations, or culinary practices. This is particularly relevant for environmental impact categories with a strong local component, such as water use or pollution, and for multi-ingredient or fortified foods whose composition may vary across regions. Likewise, the implications of proxy data depend on the study objective. For instance, in assessments focused on toxicity-related impacts, the use of generic pesticide production datasets or emission factors that do not reflect specific crops, management practices, or climatic conditions may substantially affect results and potentially lead to misleading conclusions (Nemecek et al. 2022), while the relevance could be minimal if characterizing GWP. Similarly, mismatches in system boundaries are especially relevant for foods requiring cooking, refrigeration, substantial processing, or packaging, whereas their influence may be more limited when comparing foods with similar preparation requirements. Finally, the choice of a nutrient-based FU becomes particularly important when comparing foods with different nutritional roles or nutrient densities, as mass-, energy-, and nutrient-based units may lead to different rankings and interpretations. In contrast, when the objective is to compare alternative production systems or management scenarios that are not expected to substantially affect nutrient composition within the same food product, the choice of FU is less likely to alter relative conclusions if applied consistently. Together, these examples highlight that future n-LCA studies should not treat all forms of misalignment as equally problematic but rather prioritize sensitivity analyses and transparent reporting for those assumptions most likely to influence the interpretation of results.

Therefore, although this study aimed to critically evaluate methodological frameworks and data consistency across nutritional and environmental dimensions, the relevance of a given misalignment should be assessed by its potential to influence the direction, magnitude, or interpretation of results. This perspective helps explain why full methodological alignment is not always indispensable and why efforts should focus on aspects that meaningfully affect main conclusions while retaining sufficient flexibility to adapt methodological choices to the goal and scope of the study. In many cases, simplified approaches are acceptable provided they are consistent with the study objectives. But in any case, as pointed out in this study, they should be transparently reported.

4.6 Strengths and limitations

This review is, to our knowledge, among the first to map how environmental and nutritional assessments are integrated in n-LCA studies, highlighting methodological gaps that limit comparability and policy use. Its main strength lies in its analytical depth, revealing where inconsistencies originate and how they propagate across study designs. However, this study does not constitute a formal systematic review but rather a scoping review based on a specific search strategy, initiated from Reguant-Closa et al. (2024) and complemented by snowballing and an updated search up to June 2024. Therefore, the findings should be interpreted as a structured mapping of alignment issues within the reviewed literature, rather than as a fully exhaustive assessment of the entire n-LCA field, and the possibility that some relevant studies were not captured cannot be excluded. Moreover, the concentration of studies conducted in high-income settings, particularly in European contexts, may limit the generalizability of the findings. However, given that n-LCA applications have largely emerged and been developed within these contexts, a certain degree of geographical concentration was expected. Nevertheless, this imbalance highlights the need for greater representation of studies from low- and middle-income countries to assess whether similar alignment challenges arise in those contexts, where more limited availability of nutritional and environmental data may further increase the risk of misalignment. On the other hand, although data extraction and alignment classification were conducted by multiple reviewers with expertise in nutrition and LCA, the assessment remains qualitative in nature and therefore involves a degree of interpretative judgment, which may limit its reproducibility. Certainly, uncertainties in classification arose mainly due to limited clarity and detail in the reporting of the included studies. These cases were discussed to reach consensus. Beyond representing a limitation of the present study, this issue further highlights the need for improved transparency and completeness in data reporting in nLCA studies.

5 Conclusions

This review suggests that while n-LCA offers potential to support the assessment of foods and diets from both nutritional and environmental perspectives, current applications often show methodological inconsistencies across dimensions. Lack of transparency and misalignments in data sources, product scope, and system boundaries can undermine reliance on comparability and limit confident policy relevance, particularly when results are used to support dietary guidance or decision-making. Advancing the field requires shifting from parallel nutritional and environmental assessments toward genuinely integrated frameworks that improve data and methodological choices interoperability where appropriate, transparency in the reporting, more inclusion of uncertainty assessment, and incorporate health outcomes alongside nutrient profiles and environmental indicators when relevant to the study aim. Building interoperable, context-specific databases and establishing transparent, minimum reporting standards will be essential to enhance reproducibility and generate robust, policy-relevant evidence to guide the transition toward healthier and more sustainable food systems.

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Declarations

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