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Consequences of the use or absence of life cycle assessment in novel environmental assessment methods and food ecolabels

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ABSTRACT

Ecolabels and novel environmental assessment methods are increasingly being used to evaluate the environmental impacts of food items. Some ecolabels build on life cycle assessment, a standardised method for the environmental impact assessment of products over their entire life cycle. The major challenges of life cycle assessment include its complexity in application and result communication, as well as its data intensity. The aim of this study was to compare the methods behind ecolabels to traditional life cycle assessments for evaluating the environmental impacts of food products. To this end, we (1) categorised ecolabels, (2) identified criteria describing the suitability of existing ecolabels in evaluating the environmental impacts of food labels, (3) identified main challenges of the methods underlying ecolabels, and (4) evaluated the challenges based on the criteria to answer the research question. Among the challenges, we found that merging results obtained by different methods, such as life cycle impact assessment and bonus/malus point systems, to build a composite score can risk double counting. Furthermore, certain agricultural production methods are sometimes assumed to be more environmentally friendly than others without evidence. Environmental labels focusing on one or a few selected aspects of sustainability while ignoring other relevant issues can lead to burden shifting and should be avoided. Based on our findings, we conclude that ecolabels help consumers make more sustainable purchasing decisions and create business cases for companies as an incentive to mitigate impacts, while complex research questions should be addressed based on life cycle assessment.

1. Introduction

The negative global environmental impacts caused by mankind have reached critical proportions (Rockström et al., 2009; Steffen et al., 2015). Agriculture contributes significantly to these negative environmental impacts through food production. To quantify the environmental impact of agricultural production as accurately as possible, it is necessary to employ appropriate assessment methods. Many ecolabelling initiatives use life cycle assessment (LCA) as their main starting point. Recently, Hélias et al. (2022) investigated the methods best suited for assessing the environmental impacts of food items. They found that LCA is an appropriate framework. LCA is a normalised approach that evaluates the environmental impacts of a product or process over its entire life cycle (International Organization for Standardization [ISO], 2006a, 2006b). However, limitations of LCA have been reported, including time-intensive data collection and the need for complex indicators and calculations, especially for extensive agricultural systems (Meier et al., 2015; Montemayor et al., 2022), as well as the limited coverage of relevant environmental issues that are still poorly described, such as the effects of land-use changes on soil carbon stocks and the effects of agricultural practices on biodiversity or ecotoxicity-health impacts of pesticides and contaminants (Hélias et al., 2022). In recent years, new methods (Eco-Score, 2022; Planet-Score, 2022) for assessing the environmental impacts of (food) products have been developed, with the goal of considering environmental aspects not sufficiently covered in LCA and helping consumers make more sustainable purchasing decisions (Taufique et al., 2022). The Eco-Score by Beelong (Eco-Score, 2022), for example, accounts separately for potential biodiversity loss, an impact difficult to adequately address in traditional LCA frameworks. The Planet-Score, by contrast, proposes a way to reflect on all pesticide uses associated with the product, as LCA often lacks values for the thorough assessment of all chemicals.

The results of these new environmental assessment methods are typically displayed to consumers on food packaging as sustainability labels in a simple and easy-to-understand visual format. In general, sustainability labels are designed to provide aggregated, systematically derived, and generally verified information on selected sustainability aspects of products to multiple target groups, including consumers, producers, retailers, authorities, and non-government organisations (NGOs). These labels have wide thematic coverage; for example, they can include information on the environment-, nutrition-, and health-related aspects of a product. Some food labels also cover socio-economic aspects, such as

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working conditions, animal welfare, or compliance with social legislation and rules (fair trade) (Gómez et al., 2020). However, consumers tend to link the term 'sustainability' with environmental aspects (Grunert et al., 2014), so most sustainability labels focus heavily on the environmental impacts of food products, using 'ecolabels' that provide information on some aspects of the environmental impact of a product (van Wee, 1995). In this study, we also define labels that only indicate a specific production method (such as organic production) as ecolabels.

This study aimed to assess the main challenges of using ecolabels whose methods are entirely, partly, or not based on LCA to evaluate the environmental impact of food products. Our specific objectives were to:

(i) Categorise ecolabels based on the methodology used.

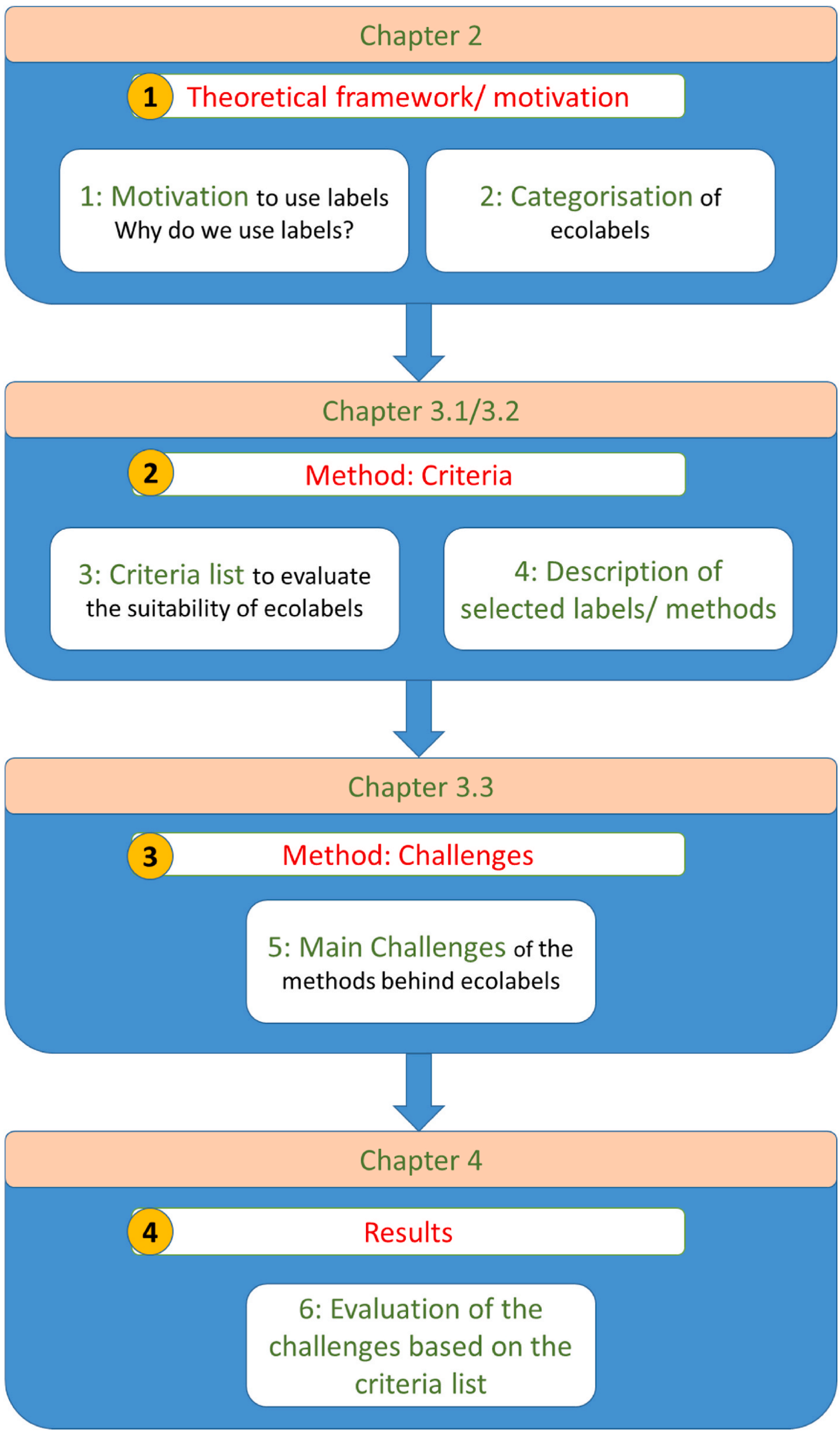

Fig. 1. Flow diagram showing the steps followed in the analysis of ecolabels.

(ii) Develop a list of criteria for evaluating the suitability of ecolabels for the environmental assessment of food products.
(iii) Identify and discuss challenges linked to the quantitative methods behind ecolabels.

The remainder of this paper is structured as follows: In Section 2, we present the categorisation of ecolabels. In Section 3, we describe the selected ecolabels analysed in this study and deduce the suitability criteria for the environmental assessment of food products based on the literature. Challenges identified with the different ecolabels are presented in Section 3, and the implication of the challenges are discussed in Section 4. The main findings and results are provided in Section 5. We present our conclusions and offer some recommendations in Section 6. Fig. 1 illustrates the four steps in the analysis.

2. Categorisation of ecolabels

Ecolabelling is an instrument for consumer information that is complementary to public policy instruments (de Haes and de Snoo, 2010), such as taxes and regulatory instruments (Ammann et al., 2023). In addition to numerous private actors, governmental bodies also launch initiatives aimed at establishing and harmonising the use of ecolabels. For example, in France, ADEME, the French Environment and Energy Management Agency, aims at launching a mandatory ecolabel on food and textile products at the end of 2024 (ADEME, 2024), or the Dutch ministry, which launched a working group to harmonise the environmental impacts of food, working towards an ecolabel (Boone et al., 2023; WUR, 2024). It is thus evident that the actors who shape ecolabels differ considerably in composition; for example, NGOs participate in the generation of around 50% of all ecolabels (van der Zee, 2022). The range of actors involved in the definition and use of ecolabels needs to be considered when identifying the motives of label developers. To identify why actors use different levels of detail when using ecolabels for communication about a product's environmental footprint, we categorised ecolabels in terms of the methodology upon which they are based.

2.1. Motivation for developing and using ecolabels

Many consumers want to distinguish food products in terms of their environmental impact (Gutierrez and Thornton, 2014; Rex and Baumann, 2007), so ecolabels should enable them to choose environmentally friendly products (Hélias et al., 2022). From a company perspective, the motivation for using or even defining ecolabels is less straightforward. Ponte (2008) identified competitive pressure as the driver for some companies to make use of labels as a signal of sustainability, while Wiese et al. (2015) pointed out that companies can gain a competitive advantage through such labelling activities. Marketing research offers ample evidence (Erraach et al., 2021; Ma et al., 2022) that a large proportion of consumers (84%, according to Janssen and Langen, 2017) appreciate sustainability labels without distinguishing between them. This could lead a profit-maximising marketeer to create a label with absolute minimum requirements and, therefore, minimum extra costs.

Gaining a competitive advantage at a low cost is not the sole motivation for ecolabel development by producers (Taylor, 2006). There is also a non-financial motivation to become more sustainable in production (Hartmann and Apaolaza Ibáñez, 2006; Mantovani and Magalhaes de Andrade, 2017; Tezer and Bodur, 2020). This can bring the company a 'warm glow' (Hartmann et al., 2017), a term used to describe a positive emotional feeling that was first applied by economists to explain donations by companies to charitable organisations and is now increasingly used in consumer research (Bronnmann et al., 2021).

If consumers choose environmentally beneficial products because they want a warm glow, it can be assumed that both NGO representatives and product managers will go for this warm glow when designing credible labels. For example, the sustainability manager of the non-dairy company, Oatly, stated that we wanted to impact consumers to drive the change. That's why we decided to calculate the climate footprint of our products with CarbonCloud: to focus on the number that drives this change (Proveg, 2023). Eventually, human motivation is always based on material and idealistic motives, but with different weightings of these on a more or less continuous scale of ideal-driven and marketing-driven activities in the creation and use of sustainability labels.

2.2. Methodologies used in ecolabelling

Ecolabels can be categorised according to the methodology on which they are based. Some ecolabels are based on life cycle thinking and provide quantitative information on the environmental impacts of food products over their entire life cycle, avoiding burden-shifting across single life cycle stages (life-cycle based ecolabels). These ecolabels can constitute proof of compliance with specified norms, preventing accidental labelling by producers (Wojnarowska et al., 2021). The system boundaries of food labelling schemes are typically from cradle to consumer; that is, they exclude consumer actions and disposal (Bunge et al., 2021). We use the term "scheme" to include both the aspects of the label's underlying method and the design of the overall framework such as criteria development, application processes, verification systems, and labelling standards. Other labels are not based on the life cycle idea and take into account only one or a few phases of the food value chain (raw material extraction, production, and manufacturing, packaging, transportation, usage and retail, and waste disposal). Many product ecolabels are limited to single life-cycle stages such as the assessment of the production and manufacturing phases. Ecolabels that guarantee certain production standards, such as fair trade and organic or rainforest protection labels, generally assess only a single stage. Such labels provide information on absolute compliance with specific criteria without further differentiating the extent to which the product exceeds a set of requirements. Other ecolabels only certify responsible and sustainable extraction and use of resources (raw material labelling); for example, the Programme for the Endorsement of Forest Certification (PEFC) label (Cadman and Cadman, 2011) considers only forest management and traceability. There is also the potential to reduce the environmental impact of a product by using recycled materials, such as recycled plastic (Burrows et al., 2022) or compostable packaging (Allison et al., 2022). Courtat et al. (2023) categorised ecolabels into three types following the ISO 14020 series on environmental labels (ISO, 1999): type I ecolabel schemes are certified environmental labelling schemes, type II refers to 'self-declarations' without third-party verification, and type III labels provide quantitative environmental information based on LCA ISO 14040 and 14044 norms. A comprehensive review of the literature by Dórea et al. (2022) found that the majority of publications have been on type I labelling schemes, but there has been an increase in the number of publications on type III labelling schemes since 2013.

In the following sections, this theoretical framework is used to identify criteria that can help evaluate the soundness of ecolabels with respect to a product's environmental sustainability.

3. Methods

In this study, we distinguished ecolabels based on (i) LCA methodology only, (ii) a combination of LCA and other methods, and (iii) a self-tailored method. Within each type, we further differentiated between ecolabels based on the number of phases of the food value chain considered up to the selling point, from a single life cycle stage to including all life cycle stages.

3.1. Criteria list

The criteria used to evaluate the suitability of ecolabels for the environmental assessment of food products vary widely. Some previous comparisons have focused on the complexity and completeness of ecolabels (Bockstaller et al., 2011), while others have examined

Table 1
List of criteria for verifying the suitability of ecolabels for the environmental assessment of food products.

Criteria	Description	Sample questions
Scientific quality	Scientific quality and soundness of the method	(i) Has the method been published in peer-reviewed publications? (ii) Is the framework supported by scientific evidence? (iii) Are the key processes parameterised sufficiently precise? (iv) Are the results reproducible? (v) Do they rely on a harmonised method?
Completeness	Coherence and completeness of the overall framework	(i) Are all environmental impacts considered? (ii) Are additional sustainability aspects (social and/or economic) considered? (iii) Are the system boundaries clearly defined? (iv) Are all life cycle stages considered (including upstream processes)? (v) Is the framework coherent?
Transparency	Availability of a full description of the entire method and required input data for all interested stakeholders and actors, including transparency on conflicts of interest and funding sources (e.g. by third parties or public funding).	(i) How transparent is the framework for stakeholders such as food processing companies, retailers, governments, NGOs and, most importantly, consumers, especially for communication purposes and decision-making? (ii) Is the framework traceable to allow external verification? (iii) Is the procedure for approval, designation, recognition, accreditation, and certification clearly described and publicly documented? (iv) If weighting has been used, are the weights used publicly available?
Verifiability and traceability	Reliability, representativeness and traceability of input data, certification through external reviews by independent third parties, data from publicly accessible databases rather than datasets not verifiable by third parties.	(i) Are the necessary input data subjected to a thorough quality check? (ii) Are the input data publicly accessible (via databases)? (iii) Are data on compliance and assessments publicly available (open data)? (iv) Was the method reviewed by a third party?
Feasibility	Implementation and operationalisation of the method, particularly time and cost of implementation and operation. Data acquisition, plausibility control, and the software tools deployed play a major role.	(i) Is technical implementation of the method feasible? What are the resource needs for implementation? (ii) Is implementation feasible with little expert knowledge? (iii) Are plausibility checks on the necessary input data sufficient? (iv) Is the necessary IT infrastructure (hard and software) available at a reasonable cost (licence)? (v) Is the operation feasible with a low time and cost requirement?
Scope ofapplication/ generalisability	Broadness of application and generalisation	(i) Can the label be applied to all relevant food products? (ii) Can the label be applied to a large number of products using ratings established on common rules?
Communicability	Degree of challenge in communicating the method to stakeholders with different levels of knowledge (we explicitly excluded visual communication, for example, traffic-light labels on food packaging).	(i) How well can the method behind the label be communicated to different stakeholders? (ii) Is the content of the label easy to understand?

user-friendliness and utility (De Olde et al., 2016). The list in Table 1 is based on the available literature and represents criteria deemed relevant when evaluating the extent to which the methodological approach used for a label is suitable for the environmental assessment of food products, focusing particularly on ecolabels and labels that merely specify the food production mode. Table 1 also provides a short description of the selected sample questions for each criterion. Six main criteria were identified:

(i) Scientific quality
(ii) Completeness
(iii) Transparency
(iv) Verifiability and traceability
(v) Feasibility
(vi) Communicability

Since our aim was to evaluate the methods behind the ecolabel rather than the motivation, we excluded criteria related to consumer behaviour. This would require extensive evaluations of the purchasing behaviour of consumers before and after launching the ecolabel and is outside the scope of the paper. Further, our aim was not to rank the ecolabels regarding the incentives for producers to show the results of their mitigation efforts. This aspect is closely linked to the question of whether the company can provide company-specific information/data to the ecolabel.

For ecolabels to be used for the environmental assessment of food products, the underlying method should satisfy the criteria listed in Table 1, which means the following:

- The system should use a scientifically sound method (high scientific quality).
- The method should include all relevant environmental impacts and life cycle stages (high completeness).
- The description of the method should be accessible to all interested stakeholders and actors (high transparency).
- The input data should be quality-checked and publicly accessible (high verifiability/traceability).
- Method implementation and operationalisation should be feasible at a low time and cost (high feasibility).
- The method should be applicable to a relevant number of food products (broad applicability).
- The method should be easy to explain to stakeholders, actors, and consumers (high degree of communicability).

3.2. Description of selected ecolabels and assessment methods used for ecolabelling

To assess the challenges associated with existing ecolabels, we selected a set of ecolabels from among the large number of ecolabels currently available, covering a broad range of methodological approaches. We make no claim to the completeness of our set and do not provide a detailed description of the methods underlying these ecolabels. Instead, we address aspects (main purpose of the label, short/concise description of the method behind the label, environmental impacts considered, key publications) relevant in the context of our analysis and provide a list of references to full reports, relevant websites, or articles for each method.

Eco-Score by Beelong (Eco-Score, 2022) is assigned to food products as a value between 0 and 100, with colour-coding across five alphabetic scores from A to E (from dark green, representing the lowest impact on the environment/society, to red, representing the highest impact). It considers CO_2 footprint, water footprint, land use, biodiversity, seasonality, endangered species and fishing method, animal welfare, distance travelled, type of transport, and packaging. Eco-Score by Beelong is based on an LCA score derived primarily from Agribalyse and other databases (Agrifootprint, ecoinvent, World Food LCA database) but modified by bonus and malus points (BMPs) that are added and subtracted from the normalised LCA score. Bonus points reward the local provenance of ingredients or third-party sustainability certifications, including Fairtrade or Rainforest Alliance. Malus points penalise, for example, non-recyclable packaging. Eco-Score by Beelong was first developed by the company Beelong, co-managed by Ecole hôtelière de Lausanne (EHL), and is constantly evolving according to the latest state of scientific knowledge. According to the Beelong website (2024), the calculation methodology is updated every two years.

Planet-Score (2022) is structured similarly to Eco-Score by Beelong. By amending LCA results using sub-indicators, it considers the impact of pesticides on human health, the effect of soil carbon on greenhouse gas (GHG) emissions, and the effects of agricultural practices on biodiversity. Planet-Score was developed under the leadership of the French Organic Food and Farming Institute (ITAB).

Carbon footprint labels such as the verified CO2e footprint label from Carbon Trust (CT, 2024) or the Carbon Neutral Product Certification (CNP, 2024) provide information on CO_2–equivalent emissions during the production and distribution of a good or service (Taufique et al., 2022). Thus, these labels do not account for environmental impacts other than the total GHG emissions caused by a particular product. Multiple approaches have been applied to the practical implementation of the carbon footprint of food products. These approaches are based on datasets with different levels of detail and methods that differ in complexity and completeness. In addition, they differ in the number of life cycle stages considered; for example, many approaches do not consider the extraction of raw material. Carbon footprints can vary in terms of which emissions they include, despite existing standards (WTO, 2021). Some only consider direct emissions from fossil fuel combustion and industrial processes, while others adopt more comprehensive approaches that include indirect emissions from land use changes. The latter approach is particularly relevant if the product assessed impacts land use.

Product environmental footprint (PEF) is a standardised method for product environmental footprinting based on different methodological assumptions. It provides a method for modelling the environmental impacts of the flows of material/energy and emissions and waste streams associated with a product throughout its entire life cycle. The method recommends applying a broad range of 16 environmental impact indicators (Commission, 2021). It also provides a set of normalisation and weighting values for calculating a single score (Ramos et al., 2022). The modelling requirements for selected food categories are defined in specific PEF category rules (PEFCRs). If no PEFCR is available, the general PEF method should be applied (Zampori and Pant, 2019). Lansche et al. (2016) showed that the PEF method makes a valuable contribution to the harmonisation of environmental product declarations, but that some methodological clarifications are needed regarding the completeness of the impact assessment methods (biodiversity and soil quality) and allocation rules. According to Pedersen and Remmen (2022), the currently available PEFCRs also have some issues related to allocation to co-products and the choice of functional unit. Boone et al. (2023) pointed out inconsistencies between product categories, while according to Zampori and Pant (2019), comparability is only possible between products of the same product category, that is, the same PEFCR is applied.

Enviro-Score is a single environmental score adapted to the European food universe based on the 16 environmental impacts provided by PEF (Ramos et al., 2022). Normalisation is based on the European Food Basket and average consumption per food item and person. Weighting factors for environmental impacts follow Sala et al. (2018), ignoring the impact categories relating to toxicity (human toxicity, cancer and non-cancer effects, ecotoxicity) because of the lack of robustness of the methodologies. Pedersen and Remmen (2022) raised critical issues, such as the weighting of the impact categories. Organic food labels such as United States Department of Agriculture (USDA) Organic (USDA, 2023) or the EU organic label (Zander et al., 2015) reward products that meet organic production rules. Organic agriculture is often considered to have a lower environmental impact than conventional farming (Lorenz and Lal, 2016; Santhoshkumar et al., 2017). This is mainly related to the reduced use of plant protection products. A meta-analysis by Tuomisto et al. (2012) concluded that "organic farms tend to have higher soil organic matter content and lower nutrient losses (nitrogen leaching, nitrous oxide emissions and ammonia emissions) per unit of field area". One major challenge in establishing harmonised organic labels is the "operationalisation" and harmonisation of the general definition of organic agriculture into a well-defined set of rules for rewarding an organic product. The International Federation of Organic Agriculture Movements (IFOAM), an organic farming organisation founded in 1972, defines organic agriculture as "a production system that sustains the health of soils, ecosystems and people". Organic agriculture relies on ecological processes, biodiversity, and cycles adapted to local conditions rather than the use of inputs with adverse effects. It combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved (IFOAM, 2023).

The **IP-Suisse label** used by agricultural producer and distributor associations in Switzerland (IP-SUISSE) rewards farm products produced in a sustainable, environmentally friendly way, focusing on biodiversity (Birrer et al., 2014), climate protection, socio-economic aspects, and animal well-being. To reduce the climate impact of farms because of GHG emissions, a point system has recently been launched to encourage implementation of selected climate protection measures, such as solar panel heating, heat recovery from milk cooling, phase-feeding in pig fattening, and covering of stored slurry. Implementation of selected GHG mitigation measures will soon become mandatory for the IP-SUISSE label.

True cost accounting (TCA) is an economic assessment method that considers the impact on natural and social capital (Michalke et al., 2022). The underlying philosophy is that food production causes external costs that are not covered by the economic market price and that human well-being is largely supported by ecosystem services. TCA takes into account social, health, and environmental externalities, or 'hidden costs', when describing the negative impacts of agricultural practices, thus allowing for internalisation of these (Baker et al., 2020). The impacts considered are (i) climate change, (ii) water pollution and scarcity, (iii) biodiversity, (iv) soil fertility, (v) social working conditions, (vi) animal welfare, and (vii) consumer health. The method benefits from its simplicity in communicating its results, allows aggregation on a monetary basis, and is widely applicable. The method is suited to account for all environmental (e.g. air and water pollution, biodiversity loss, social (e.g. health impacts), and ethical (e.g. animal welfare) externalities by monetisation of all external costs. However, in practical applications, TCA may suffer from oversimplification (e.g. only pesticides have an impact on human health), and some criticise it and other monetisation approaches since some values are non-tradable (Bruel et al., 2016) and it is difficult to assign monetary values to human health or biodiversity (Pizzol et al., 2015). Furthermore, while communicating TCA results might seem simple, their interpretation is difficult. Finally, TCA is still under a lot of development, and there is not yet an accepted and standardised method. We base our analysis on the general principle that TCA monetises social and environmental externalities.

In a thorough methodological review of these ecolabels and expert group discussions, we identified major challenges in the underlying methods for these ecolabels. Each of these challenges was evaluated against the criteria listed in Table 1 to objectively infer the implications for the suitability of the ecolabel for the environmental assessment of food products. The challenges are described in the next section.

3.3. Challenges with the methods used in ecolabels

Table 2 lists the challenges identified in the methodological approaches underlying the selected ecolabels, grouped into the following four categories: (i) aggregation, (ii) simplification, (iii) prejudice, and (iv) subjectivity.

3.3.1. Challenge 1: Aggregation

Ecolabels often aggregate different sustainability impacts or scores obtained from different methods into a single value. Such aggregation is a common challenge in ecolabel methods and takes one of three forms:

a) *Aggregation based on weighting*: LCA provides approaches for aggregation into endpoints by modelling damage to human health, ecosystem quality and resource scarcity, based on comprehensive cause-effect chains (e.g. ReCiPe2016, Huijbregts et al., 2017; or ImpactWorld+, Bulle et al., 2019). Alternatively, normalisation and weighting of values can be used to compute a single score from individual midpoints. The composite indicator then depends on the weights of individual sub-indicators, which means that a detailed description of the weighting procedure is crucial. Note that weighting always means applying value judgement.

A great variety of weighting methods, such as panel weighting methods, monetary valuation (willingness to pay), or distance-to-target methods, are available (see, e.g. Ahlroth, 2014), but they all include a strong subjective component. Although these methods are scientifically derived and have long been widely used, numerous labels have developed their own schemes explicitly or implicitly. Some implicitly incorporate weighting because they require compliance with a certain percentage of predefined criteria covering both environmental and socioeconomic aspects. For example, the label 'Rainforest Alliance' requires fulfilment of 80% of 94 criteria, ranging from water pollution control, conservation of ecosystems and natural habitats to socioeconomic aspects such as fair working conditions and health and safety requirements at work. Eco-Score by Beelong gives 'climate & resources' a weighting of 36%, production methods 32%, origin (direct impact on transport distance) 23% and level of processing 9%, without clear justification behind each weight. Enviro-Score relies on an openly accessible weighting set specific to European stakeholders.

b) *BMPs and LCA (double counting)*: The BMPs used in Planet-Score and Eco-Score by Beelong, in addition to LCA, result in problematic double counting. Planet-Score penalises irrigation during dry periods, among other things, but this aspect is fully covered by available LCA methods, such as AWARE (*A*vailable *WA*ter *Re*maining), a consensus-based method developed to assess water use in LCA (Boulay et al., 2018). In addition, the production of vegetables in heated greenhouses and transport are both penalised by malus points, despite their potential environmental impacts being well covered by, for example, global warming potential (GWP) according to IPCC (2021). The same applies to bonus points awarded for local production. Further, Eco-Score by Beelong may overweigh the aspect of biodiversity by awarding additional bonus points for food products that have been already certified by other labels such as Demeter, Rainforest Alliance, Fairtrade, Label Rouge, Aquaculture Stewardship Council (ASC), or Marine Stewardship Council (MSC).

c) *BMPs and LCIA (aggregation)*: Calculation of a composite score by merging scores from LCA and BMPs involves adding scores from different methods. Because there is no common scale for these two approaches, aggregation is difficult. Furthermore, the number of additional (negative or positive) points awarded per BMP score does not rely on established scientific principles. For example, Eco-Score by Beelong rewards short transport distances of ingredients with up to 15 points, but the impact on biodiversity related to the depletion of fish stocks and deforestation is limited to a maximum of 10 malus points.

3.3.2. Challenge 2: Simplification

Methods can be simplified in different ways, for example, by reducing the number of environmental impacts considered or the number of life cycle stages considered, or by simplifying the representation of physical processes or the use of generic data.

a) *Limitations of selected environmental impacts:* Numerous labels focus on certain environmental aspects of the product, such as energy consumption or water use, while ignoring other environmental impacts, risking burden-shifting. Examples are the carbon footprint label (Lemken et al., 2021), which focuses on average GHG emissions per food item, and the water footprint label, which provides detailed information on the total volume of freshwater used (Nydrioti and Grigoropoulou, 2022).

b) *Single-stage life cycle*: LCA follows the 'cradle-to-grave' approach by including extraction and processing of raw materials and processing, packaging, transportation, or distribution of the product to the consumer, which avoids shifting the environmental burden from one stage or process of the life cycle to another. However, several ecolabelling schemes only consider certain life cycle stages, such as the production phase, while ignoring all environmental impacts because of purchased fertilisers, machinery, or infrastructure. Certain ecolabelling systems focus on the environmental impacts from the production, use, and disposal of packaging, for example, rewarding recycled materials (Donato and D'Aniello, 2022). For example, the Forest Stewardship Council certifies paper or cardboard packaging material that comes from responsibly managed forests. Other labels such as MSC and ASC labels focus on the production phase: ASC guarantees a high standard for sea food farming regarding aquaculture practices (ASC, 2024), while MSC ensures best practices in fisheries management (MSC, 2024). The aspect of short transport

Table 2
Challenges with current ecolabelling methods and selected examples for illustration purposes.

Challenge	Individual issues	Selected examples for illustration
1. Aggregation	a) Aggregation based on weighting b) BMPs and LCA (double counting) c) BMPs and LCA (aggregated)	• Eco-score by Beelong (Eco-Score, 2022) • Planet-score (Planet-Score, 2022) • Enviro-score (Ramos et al., 2022)
2. Simplification	a) Limited to one (or a few) specific environmental aspects b) Restricted to single stage of life cycle c) Process-type labels d) Insufficient scientific basis e) Uses generic data instead of company-specific data	• Carbon footprint label • True cost accounting (Michalke et al., 2022)
3. Prejudice	Critical prejudice	Organic labels, for example: • United States Department of Agriculture (USDA) Organic (USDA, 2023) • EU organic (Zander et al., 2015)
4. Subjectivity	Interest-driven	• Single PEFCRs, Planet-Score

distances (transportation) is covered by numerous labels focusing on local production, such as 'Regionalfenster', a label used in Germany that provides reliable orientation on the regional provenance of foods.

c) *Process-type labels*: Most current labelling schemes involve 'process-type' labels and do not provide any information on the degree of goal fulfilment for the goals assessed, but rather whether the conditions of the label are fulfilled or not. These labels are good for quick consumer information but at the expense of the information content, and do not reward products that go far beyond the given label's requirements. This provides less incentive to improve production methods to lower negative environmental impacts.

d) *Insufficient scientific basis*: Some certification schemes suffer from insufficient scientific basis, and in general, the methodology applied to various labels could be improved. TCA, for example, is based on oversimplified assumptions to allow monetisation. The estimation of avoidance costs (of replacing existing technology with greener technologies) is subject to considerable uncertainties (de Adelhart Toorop et al., 2023). In addition, there is insufficient transparency regarding the monetisation of ecological indicators. Note, however, that there is not yet one broadly accepted and standardised TCA method, and much development is still underway.

e) *Use of company-specific (primary) and generic (secondary) data*: Company-specific data refers to directly measured or collected data that is representative of the company or the producer (also called 'primary data'), while secondary data is generic (background) data, mostly taken from a third-party life cycle inventory (LCI) database or other sources. Operationalisation and implementation of an ecolabel can benefit from using generic data instead of company-specific data by avoiding time-consuming data acquisition. Producer-specific data generally allow for a more precise and accurate assessment of each product's unique characteristics, thus improving the informative value of the ecolabel. However, Weidema and Eliassen (2023) stressed that in some standards and guidelines, the primary data requirements go beyond what can be justified because, in reality, they cannot be known with that level of precision. Pederson and Remmen (2022) stated that the PEF method requires company-specific data for all known inputs and outputs from the process, so that "too many requirements for primary data could become a barrier to using the PEF method".

To achieve a simpler and less data-intensive operationalisation, LCA-based ecolabels often use generic data from databases such as Agribalyse, Agrifootprint, ecoinvent or the World Food LCA database. For example, Eco-Score by Beelong relies heavily on the average environmental impacts of different food categories from the Agribalyse database, while primary data on packaging is collected directly from the manufacturers. This also applies to the origin of the ingredients, which are used to adjust the score by accounting for transportation and regional agricultural practices. Planet-Score, while being similar to Eco-Score by Beelong in terms of the use of the Agribalyse database, gathers specific pesticide data directly from farmers or suppliers. Information on agricultural practices, which have an impact on local biodiversity, is also collected at the farm level or through third-party audits.

3.3.3. Challenge 3: Prejudice

Prejudice tends to arise if the method underlying an ecolabel does not attempt to measure the environmental impact using modelling approaches, and the ecolabel is instead based on the assumption that its underlying claims will automatically lead to favourable (low) environmental impacts. Labels without third-party verification (type II labels; Courtat et al., 2023) are particularly prone to prejudice, because no experts can guarantee what the label promises. For example, organic farming has a very positive image in Europe because of claims that organic farming leads to more environmentally friendly and more sustainable production (Mercati, 2016; Seufert et al., 2017). In their systematic review, Boschiero et al. (2023) showed that organic systems have a statistically significantly better environmental performance than conventional ones for most impacts, such as climate change, ozone depletion, ecotoxicity, human toxicity, and use of resources (abiotic, mineral, and metal), regardless of the functional unit used (mass or land-based). However, other LCA studies have shown that some environmental impacts, such as GWP, eutrophication, and acidification, are—for certain products—higher per kg of product in organic systems because of the typically lower yields compared with conventional farming (Nemecek et al., 2016). Thus, an 'organic' label may not mean "what consumers may think it means" (Czarnezki, 2011).

3.3.4. Challenge 4: Subjectivity

The methodological approaches behind ecolabels may suffer from subjective decisions by interested stakeholders, parties, and associations. Subjectivity is closely related to the interest-driven formulation of procedures and methods, which may hamper the use of methods based on sound scientific data or widely supported and generally accepted knowledge. Ideological motivations to influence consumer decision-making (e.g. on regional production or recycling habits) by intentionally giving higher weights and/or double counting a certain aspect are also subjective and should be avoided. Several current ecolabels suffer from subjective decisions in the methodology, including Planet-Score and PEFCR. Actors whose products are assessed by these ecolabels are directly involved in the elaboration of the method, either as the author (Planet-Score) or via negotiations (PEFCR). For this reason, despite the rigorous multi-stakeholder underlying process, PEFCR is considered by Weidema and Eliassen (2023) as a political process. Various private-sector players were involved in setting the rules, with most presumably pursuing their own business interests. Weidema and Eliassen (2023) stressed that the allocation rules are inconsistent across PEFCRs; thus, using PEFCRs to model an overall system that spans the valid range of more than one PEFCR may result in inconsistent results.

4. Results

In this section, we describe the implications of the challenges associated with ecolabel methods for their suitability for the environmental assessment of food products. The implications of the challenges listed in Table 2 for different suitability criteria in the environmental assessment of food products are presented in Table 3.

4.1. Aggregation – weighting

Weighting is crucial to obtain aggregated scores, and thus easier interpretation and communication of the overall impact. However, this is often achieved at the expense of scientific robustness, as weighting often has a subjective component, and there are many different weighting methods. For these reasons, we rated the criteria "communication" and "scientific robustness" for weighting as positive (green) and negative (red) scores, respectively (see the first row in Table 3). The other criteria are rated neutral (0, yellow) for the challenge of "weighting" because the evaluation depends strongly on the method and documentation provided.

4.2. Aggregation – BMPs

Scientific robustness is impaired by double counting because it undermines physical and scientific principles. However, because BMPs allow for the consideration of aspects not covered by LCA, they may improve completeness. For example, exposure to potentially harmful mixtures of pesticides ('cocktail effects') (Rizzati et al., 2016) or land use impacts on pollinator abundance have not yet been implemented in current models used in LCA in a satisfactory manner, despite promising models recently being suggested (Alejandre et al., 2022). Adding BMPs to the computation of a single score has a negative influence on the

Table 3
Evaluation of challenges listed in Table 2 based on the evaluation criteria in Table 1. Symbols: +: criteria is positively affected; 0: neutral/only slightly affected/no judgement possible; -: criteria is negatively affected. Note that the rating is partly subjective and also depends on the label.

	Scientific robustness	Completeness	Transparency	Verifiability	Feasibility	Applicability	Communication
Aggregation							
- Weighting	-	0	0	0	0	0	+
- Bonus/Malus points & LCIA (aggr./double counting)	-	+	-	-	+	+	-
Simplification							
- Limitation to one or few environmental impact	0	-	0	+	+	+	+
- Single stage of life cycle	0	-	0	+	+	+	+
- Process type labels	0	-	0	+	+	-	+
- Insufficient scientific basis	-	-	-	-	-	-	-
- Use of generic input data instead of company-specific data	-	0	0	+	+	+	0
Prejudice	-	-	-	-	0	+	+
Subjectivity	-	0	0	0	-	0	0

transparency of an ecolabel. Communication is generally negatively affected by the use of BMPs because it is challenging to communicate the simultaneous use of different methods (BMPs and LCA) to the wider public. By contrast, BMPs tend to increase feasibility and applicability because they avoid the use of additional complex models, thus potentially facilitating technical implementation of the ecolabel and avoiding time-demanding data acquisition and plausibility checks. However, a pertinent question could be whether environmental assessments based on generic (company-unspecific) data should be the target, as it then becomes difficult for companies to show the results of their mitigation efforts (e.g. all milks start with the same LCA score before applying BMPs).

4.3. *Simplification*

In general, ecolabels based on insufficient scientific data adversely influence all criteria, except scientific robustness. The scientific robustness of the ecolabel may be challenged when justifying why important aspects have been ignored; except for the challenge of "insufficient scientific basis", the influence of simplification on scientific robustness is neutral. For ecolabels based on other simplified methods, simplification generally leads to increased verifiability, feasibility, and communication of the method (Table 3). For the latter, focusing on certain aspects or simplifying the driving processes can reduce the knowledge required to understand the ecolabel's method. By contrast, applicability may be adversely affected if the label can only be awarded to a very limited set of product or product categories. Simplification generally leads to decreased completeness, because it tends to ignore the processes and aspects contributing to the total environmental burden of a food product. Given that the necessary documentation is provided for the method, transparency is likely not affected by the simplification of ecolabels. The use of generic data generally has a negative impact on scientific robustness, as specific local properties are ignored. By contrast, its use increases the feasibility and applicability of the ecolabel, as time-consuming primary data acquisition (and storage) can be avoided. Metrics based on generic data (e.g. from harmonised databases) increase applicability, allowing their use for a broad range of products, countries, and application methods. The label's guidelines seldom provide strict guidelines but tend to encourage users to prioritise detailed foreground data.

4.4. *Prejudice*

Ecolabel methods suffering from the prejudice challenge are of low scientific quality because they do not rely on published scientific methods. These ecolabels often only describe the production method or address a partial aspect, leading to a generally low degree of completeness. In contrast, feasibility is generally high because of simple and cost-effective operationalisation. The same applies to communication, because the method behind the ecolabel can easily be explained and understood by consumers, with the ultimate goal of motivating a consumer to purchase the labelled product.

4.5. *Subjectivity*

The influence of subjectivity on completeness, transparency, verifiability, applicability, and communication seems to be neutral, although scientific robustness is impaired by subjectively derived labels because the method tends to lack scientific evidence.

5. Discussion

This study assessed the methods behind ecolabels to (1) deduce criteria for evaluating their suitability for the environmental assessment of food products and (2) identify and discuss challenges linked to the use of existing ecolabels for the environmental assessment of food products based on the defined criteria. The results suggest that the growing number of labelling schemes present in the food market differs widely in terms of information quality. The evaluation of the challenges (Table 2) based on the criteria (Table 1) revealed that the method behind ecolabels often does not allow for a comprehensive assessment of the environmental impact caused by the production of the food items (Table 3). The reasons for this include incomplete coverage of environmental impacts, weak scientific basis due to poor methodology or a lack of harmonisation in the emission models used, lack of transparency, and (hidden) commercial interests of stakeholders.

Analysis of the methods behind environmental labels revealed that LCA is still not generally used or, if used, it is often complemented by other methods, such as BMPs. This is primarily because of the complexity and data intensity linked to LCA. The large number of physical processes considered, for example, in the computation of GHG emissions and nutrient fluxes, requires the collection of a large amount of data. To increase the reliability of the results, several ecolabel companies recommend the use of company-specific data. To achieve reliable results, extensive plausibility controls and verification of the data are also essential. Automation of these checks might be possible.

Furthermore, weighted LCA results can be influenced by the subjective views of society and its different perceptions (Lueddeckens et al., 2020). LCA-based ecolabelling methods benefit from a systemic approach to analysing the environmental impacts of products during their entire life cycles and covering a wide range of environmental impacts. However, modelling linked to these environmental impacts can suffer from shortcomings, for example, inadequate nitrogen models and thus incorrect estimation of nitrogen emissions (Meier et al., 2015), failure to consider effects of combined exposure to toxic pesticide substances ('cocktail effects') on human health (Drakvik et al., 2020), or incomplete assessment of the impacts of land use on biodiversity (Winter et al., 2017). Subjectivity can be minimised using a scientifically widely accepted and supported approach (Dijkman et al., 2018). Credibility can be increased by approving reputable third parties (expert panel, scientific community, administrative authority), thus avoiding consumer scepticism. This is likely to promote confidence among many stakeholders, such as food processing companies, retailers, and consumers.

Our analysis showed that awarding additional credits to food products that have already been rewarded by another label from a third-party organisation should be avoided because it increases the probability of double counting, as also pointed out by Hélias et al. (2022). It is especially critical to avoid awarding additional bonus points to an ecolabel of food items (e.g. Eco-Score by Beelong) based on other labels that (directly or indirectly) already include aspects such as the impact of land use change, resource depletion, biodiversity, or soil quality. Most of these impacts can be accounted for by widely used LCA methods. For example, the LCA endpoint method ReCiPe considers biodiversity damage as the potentially disappeared fraction (PDF) of a species in a given region based on the diversity of vascular plants (Huijbregts et al., 2017). An approach proposed by Chaudhary et al. (2015), although differentiating little between various land-use types, is well suited for computing ecoregion-specific marginal and average characterisation factors for assessing biodiversity loss from both land occupation and transformation. Note that the above-mentioned methods would require adaptations to account for specific farm-management practices such as soil management, crop rotation, nutrient, pesticide, and livestock management (as done, e.g. in the Swiss Agricultural Life Cycle Assessment [SALCA] model; Nemecek et al., 2023).

Another criticism is whether it makes sense to supplement LCA-based labels with additional benefits for organic agriculture. There are conflicting opinions on whether LCA is appropriate for fully describing organic farming (Montemayor et al., 2022). These authors also claim that local soil, climate, and land management practices should be better accounted for. Some studies claim that the current state of LCA does not represent all relevant aspects of organic production, because of limitations, gaps, and inconsistencies in the datasets of plant protection products and fertilisers (Meier et al., 2015; Montemayor et al., 2022; van der Werf et al., 2020). Others recommend that the assessment should include, for example, land degradation, biodiversity, and pesticide impacts in LCAs of organic farms (van der Werf et al., 2020), or even ecosystem services, to better account for the multifunctionality (e.g. provision of ecosystem services to society) of organic farmland (Meier et al., 2015). Recent studies have proposed approaches to such integration (De Luca Peña et al., 2022). However, except for ecosystem services, current state-of-the-art LCA methods account for most of the above-mentioned aspects (Nemecek et al., 2023). Therefore, the tendency to use BMPs to 'correct' and adapt outcomes to meet the expectations of specific stakeholders can be criticised, as long as the BMPs do not allow to cover aspects not covered with LCA. BMPs are useful to include aspects that are not included in LCA such as animal welfare.

Ecolabels that only consider selected environmental impacts are problematic because they are often called 'sustainability labels', despite treating a very limited part of overall sustainability, including all three dimensions (environmental, economic, and societal). For example, Fairtrade International claims that it 'is the most recognised and trusted sustainability label in the world' (Fairtrade, 2023), while UTZ (2023) claims that its label fosters 'sustainable farming and better opportunities for farmers' for coffee, cocoa, tea, and hazelnut products. Unfortunately, this less precise and casual application of the term 'sustainability labels' can be found in numerous publications. Another criticism is that implementation of the concept 'sustainability' differs significantly between ecolabels (Ammann et al., 2023). For example, some consider it sufficient to address limited aspects of sustainability while claiming to address the sustainability of production or a product. This causes confusion among consumers and hinders comparisons of the information value of different labelling schemes.

To avoid any burden shifting arising from focusing on single environmental impacts like climate change, label organisations should consider other impact categories such as soil quality, biodiversity, and pesticide use (Nemecek et al., 2011; Roesch et al., 2021). Wherever possible, this goal should only be achieved by improving existing LCA methods rather than awarding BMPs. Furthermore, it is crucial to consider positive impacts through the provision of ecosystem services. Promising approaches to incorporating ecosystem services into LCA have been developed in recent years (Alejandre et al., 2019). A review by Peña et al. (2022) on the use of LCA and ecosystem services assessment to allow comprehensive assessment of the positive and negative impacts of human activities on ecosystems highlights the risk of double counting because of overlapping indicators. Focusing on selected aspects of sustainability (of a production method or food product) hinders the assessment of the overall sustainability of entire value chains when considering both environmental and socio-economic issues. Thus, synergies and trade-offs between different sustainability aspects cannot be identified and analysed.

In light of the above discussion, environmental labelling methods should be based on the LCA approach to ensure a coherent method that considers upstream processes and allows for the appropriate definition of system boundaries. This requires strong efforts and initiatives to generate, structure, and disseminate LCA data. This process has already begun with the establishment of open-access databases for LCI data (Clark et al., 2022; Fritter et al., 2020; Ghose et al., 2019; Henriksson et al., 2022; Kahn et al., 2022). Special emphasis must be placed on closing methodological gaps, such as including ecosystem services and appropriately considering the effects of toxic substances on human health.

Several recent ecolabelling initiatives aim to develop leading-edge tools based on the latest scientific research and broadly accepted ISO standards. For example, HowGood's research methodology (HowGood, 2024) focuses on agricultural production to consolidate findings from over 600 accredited data sources, including numerous LCA studies, reports, and aggregated commercial databases, with the aim of automating carbon footprinting to scale. Inoqo (2024) focused on climate change impact, delivering results for all life cycle stages (agricultural production, processing, packaging, transport, storage, and end-of-life) individually. Inoqo provides a platform for estimating the GWP of agricultural products by enhancing publicly available data with non-public primary data to refine the results.

The operationalisation of new refined ecolabelling methods based on LCA poses significant IT challenges, as it generally requires managing large volumes of data, ensuring interoperability between different databases, and maintaining data security and accuracy. Advanced software solutions (such as HowGood and Inoqo), data management systems, and computational tools are necessary to handle these challenges effectively.

6. Conclusions and outlook

The number of ecolabels appearing on products worldwide is constantly increasing. At the same time, LCA is an established ISO-based method for evaluating the environmental impact of products. Thus, it is important to evaluate under which conditions ecolabels, whether based on LCA or not, can be useful for evaluating the environmental impacts of food products compared to the data- and time-intensive LCA method. As a first step towards this goal, this study has deduced a comprehensive list of criteria to analyse under which conditions ecolabels can be used to evaluate the environmental impacts of food products. In addition to a broadly supported, comprehensive, and transparent scientific basis, factors relating to feasibility (operationalisation and use of plausible and falsification-proof input data) and communicability to the affected stakeholders proved to be particularly important.

Second, we identified four key challenges that need to be considered in the methodological development of ecolabels. Third, we explicated these challenges based on the criteria identified in the first step. Using concrete examples of existing labels, critical points were identified and discussed based on our list of criteria. We conclude from the analysis that the greatest caution is needed to avoid double counting when aggregating different methodological approaches and to prevent subjective assumptions about existing agricultural practices. Aggregation of LCA results with other scores may lead to double counting, thus undermining scientific robustness and leading to a lack of transparency. Subjectivity in labelling methods based on the preferences of stakeholders and organisations is likely to undermine credibility and trust in ecolabels in the medium and long term.

To summarise, ecolabels can help inform consumers by facilitating communication about the method used and the results, hence increasing method feasibility and applicability. However, current European sustainability labels for products (such as Eco-Score by Beelong or Planet-Score) tend to overweigh certain aspects without a sound scientific basis and should provide additional data on, for example, production standards and origin, as separate information instead of adding them to a single score, thus risking double counting. As such, ecolabels are, therefore, not suited to answer research questions. LCA, by contrast, is well-suited in those cases, despite its high data requirements, high complexity, and use of sophisticated software. Based on our analysis, we recommend that ecolabels' methods should be based on the LCA approach whenever possible, particularly because existing gaps in the environmental impacts calculated by LCA are closing rapidly. To avoid complex computations and to minimise temporal workloads, existing databases, such as Agribalyse or ecoinvent, should be used. The data contained in these databases should be expanded and kept updated to anticipate novel technical developments and improved farm management. Several recent ecolabelling initiatives go far beyond the use of generic databases, as the data are supply-chain specific and usually have a particular scope, for example, a region, sector, or a particular life cycle stage, which in turn allows companies to differentiate themselves from the competition.

CRediT authorship contribution statement

Andreas Roesch: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Conceptualization. **Mélanie Douziech:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Stefan Mann:** Writing – original draft, Methodology, Conceptualization. **Jens Lansche:** Writing – review & editing, Methodology. **Gérard Gaillard:** Writing – review & editing, Conceptualization.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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