Sustainable food profiling models to inform the development of food labels that account for nutrition and the environment: a systematic review

Anne Charlotte Bunge, Kremlin Wickramasinghe, Jessica Renzella, Michael Clark, Mike Rayner, Holly Rippin, Afton Halloran, Nia Roberts, João Breda

Sustainable food profiling models (SFPMs) are the scientific basis for the labelling of food products according to their environmental and nutritional impact, allowing consumers to make informed choices. We identified ten SFPMs that score individual foods according to at least two environmental indicators, with the most common being greenhouse gas emissions (n=10) and water use (n=8). Six models additionally assessed the nutritional quality of foods and presented different methods to combine nutritional and environmental indicators. Key advantages of identified models include a wide range in system boundaries, reference units, approaches for defining cutoff values, design proposals for food labelling schemes, and the comprehensive geographical scope of the lifecycle inventory databases used in the development phase of the model. Key disadvantages of identified models include inconsistent methods for food classification and poor replicability due to unclear methods, unavailable code for environmental and nutritional impact calculation, and unclear cutoff values. We found that few SFPMs to date account for at least two environmental impact factors, and even fewer include nutritional values or other dimensions of sustainability. This systematic review highlights the need to use consistent components and to develop national and international reference values for the classification of sustainable food to enable standardised food labelling.

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NCD Office, World Health Organization, Moscow, Russia (A C Bunge MSc, K Wickramasinghe DPhil, H Rippin PhD, A Halloran PhD, J Breda PhD); **Stockholm Resilience Centre, Stockholm, Sweden** (A C Bunge); **Nuffield Department of Population Health, University of Oxford, Oxford, UK** (J Renzella MPH, M Clark PhD, Prof M Rayner DPhil, N Roberts MSc); **Department of Nutrition, Exercise and Sports, University of Copenhagen, Copenhagen, Denmark** (A Halloran)

Correspondence to: Dr Kremlin Wickramasinghe, NCD Office, World Health Organization, Moscow 125009, Russia **wickramasinghek@who.int**

Introduction

Identifying and promoting dietary patterns that enhance overall diet quality and health outcomes within planetary boundaries requires consumers to make informed choices.[1] Modern industrialised food systems are associated with poor public health outcomes and exceed planetary boundaries.[2] Suboptimal diets are the leading global cause of morbidity and mortality[3] and caused, in 2017, over 950 000 deaths and 16 million disability-adjusted live-years in the EU.[4] Furthermore, the production and consumption of food products is responsible for 30% of total greenhouse gas emissions, is a major driver of biodiversity loss, occupies 50% of habitable land, and accounts for 70% of freshwater withdrawals.[5] If current food consumption patterns in G20 countries were adopted globally, the planetary boundary for food-related greenhouse gas emissions would be exceeded by 263%, by 2050.[6] Providing adequate nutrition within planetary boundaries is therefore vital to achieving international health and environmental targets, such as those included in the UN Sustainable Development Goals and the Paris Agreement.[6,7]

Supplying only food products that are adequate for human and planetary health does not, however, necessarily allow consumers to choose these products. To support consumers in making informed choices, front-of-pack nutrition labelling has proven effective in guiding consumers towards shifts to healthier food choices.[8,9] Over the past 5 years, numerous modelling analyses on how to build sustainable food systems[10] and identify sustainable diets[11] have been developed. However, these analyses are difficult to transfer to the microlevel of individual food products. Interest in labelling food products according to different dimensions of sustainability is growing.[12] With the release of the Farm to Fork Strategy in May, 2020, the European Commission is planning to develop a sustainable labelling framework that covers the nutritional, environmental, and social aspects of food products.[13]

To classify or rank foods according to their nutritional composition and environmental impact, sustainable food profiling models (SFPMs) are required. They serve as the scientific basis for labelling food products to

Key messages

- We provide a synthesis of methods and databases to choose or construct sustainable food profiling models as the scientific basis to establish national or international sustainable nutrition-related policies
- The results of this systematic review contribute to the resolution of several open questions regarding the compatibility of nutritional and environmental values and the integration of nutrition and health aspects in environmental assessments of food products, featuring regional specificities, deriving cutoff values for classification, and transforming lifecycle assessment results into easily understood information tools
- We present a novel scoring system for model replicability as a key quality metric to facilitate the comparison of models
- Moving forward, research is needed that focuses on the development of absolute reference values for classifying foods as sustainable and consistent methods to enable a standardised comparison among food products
- With an increasing number of sustainable food labelling schemes and national dietary guidelines incorporating dimensions of sustainability, sustainable food profiling models are an essential tool to provide the evidence base for environmental and nutritional assessments of foods and should therefore be further developed

guide consumers, and for regulators to set standards and criteria for product reformulation, marketing, and taxation of food products.[14] To date, no nationally or internationally agreed-on SFPM to label food products exists, but consistent ranking schemes are important to compare foods in a national and international context.[15]

Only a few SFPMs have been developed, with most of them focusing only on greenhouse gas emissions as an indicator of environmental impact[16–18] and excluding the burden of other environmental consequences related to food production and consumption. Previous systematic reviews have focused on methods to assess sustainable diets, food systems,[19–22] and nutrient profile models, assessing solely the nutritional quality of foods rather than of SFPMs.[23] The overall aim of the present systematic review is to identify SFPMs that have been developed to assess at least two environmental indicators and optionally also the nutritional content, their characteristics and components, algorithms for calculations, and cutoff values or ranking methods for classification. The underlying rationale of this work is to assist public health agents in obtaining the necessary information to choose or develop a tool to establish front-of-pack food labelling to support population health and environmental sustainability.

Methods

Search strategy and selection criteria

We conducted a systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses reporting guidelines.[24] The protocol was previously published in the Prospective Register for Systematic Reviews with the number CRD42020186436. Searches were carried out by NR on May 4, 2020, in four databases (Cochrane Library, Commonwealth Agricultural Bureaux Abstracts, MEDLINE, and Web of Science Core Collection) and on June 10, 2020, in Google Scholar with the search terms ("food" OR "diet" OR "nutrition" OR "nutrient" OR "menu") AND ("profile" OR "profiling" OR "labeling" OR "labelling" OR "footprint" OR "evaluation" OR "assessment") AND ("sustainable" OR "sustainability") AND ("model" OR "framework" OR "score" OR "scoring" OR "tool" OR "metric"). Further details of the literature search can be found in the appendix (pp 2–6). No restrictions were placed on the type of study design or publication language. However, only those that included SFPMs with development details available in English, German, or Swedish were included. Searches were limited to articles published between Jan 1, 2000, and May 31, 2020.

See Online for appendix

In the context of the private sector's growing involvement in the development of smartphone applications to promote sustainable eating behaviours, extensive research was conducted in grey literature databases. We searched OpenGrey and Ecosia (between May 4 and June 5, 2020), using the same search terms and restrictions as for peer-reviewed literature. Systematic reviews were not included, but their reference lists were screened for additional publications. Where the eligibility of the models remained uncertain, we contacted the authors with a set timeframe and considered responses up to Oct 31, 2020. Ten of the 17 authors contacted replied and provided details of the models, five of which met the inclusion criteria and were included in the final analysis. We included approaches that enabled the calculation and ranking of the environmental or environmental and nutritional impact of individual food products and excluded models that focused exclusively on nutrition, mainly because other systematic reviews that provide an extensive overview of nutrient profiling models are available in the published literature.[23] Models that scored diets, meals, or food systems exclusively were also excluded because such models are not developed to inform individual food labels. To ensure that we did not exclude models that have been tested and published on a meal or diet level but that could be feasible to assess individual foods, we contacted the study authors to verify the scale of the models we were uncertain about. Previous studies have advocated for a more comprehensive perspective on sustainability,[19,22] and therefore we excluded approaches that focused only on one environmental indicator. The inclusion and exclusion criteria are described in figure 1 and are detailed in the appendix (p 8). Title, abstract, and full-text screening was done by one author (ACB), with a multistaged subset check (of 10% of all articles) by a second investigator (JR). Contradictory and inconclusive assessments were discussed and resolved with all authors at the abstract and full-text screening stage.

Data extraction

Data extraction was done for all included models between July and October, 2020, by one investigator (ACB) with constant feedback on the extraction process and extracted content from all co-authors. Extracted information was divided into four categories. First, characteristics related to the development of SFPMs, including name, type and name of organisation that developed the model, and its year of introduction. Second, the basic components of SFPMs, including the range of food items or categories that can be ranked by the model, the geographical scope, components (ie, nutrient values and environmental impact factors), the reference amount (eg, per 100 g or per 100 kcal), and system boundaries. Third, we gathered information on the different methods used by the developers of the models to assess the health and environmental impact of food items, including their use of nutritional and lifecycle inventory databases and the algorithms for impact calculations. Fourth, information was collected on how the ranking was done, including cutoff values, scoring systems, and type of score. A detailed overview with all extracted data is available in the appendix (pp 16–21). Many tools, most of which focus on the risk of bias, are available for the assessment of the quality of studies included in a systematic review. These traditional study quality assessment approaches were not suitable for our review of models. Because a key outcome of this study is to identify food profiling models that could be replicated and thus used to inform nutrition and environmental labels, we have instead appraised the replicability of included models as a key quality metric to facilitate the comparison of models. The replicability criteria used were developed by MC and further refined by JR and ACB, and are detailed in the appendix (p 22). ACB did the initial replicability assessment and discussed any discrepancies with JR and MC, who independently assessed the models against the replicability criteria.

Results

A total of 2104 articles were retrieved from the initial search: 2080 records from peer-reviewed literature databases and search engines; 18 articles from reference lists of systematic reviews; and six articles from grey literature search tools. After excluding duplicates and animal studies, a total of 1493 studies remained, from which 88 full-text articles were assessed against the eligibility criteria. The reasons for the exclusion of publications and models in the full-text assessment stage are detailed in the appendix (pp 9–15), but the most common reasons for exclusion were articles (n=41) and models (n=2) that were designed to assess food systems, diets, or meals and that did not allow the profiling of individual food items. We also excluded 31 lifecycle inventory databases or publications that presented a method to assess the environmental impact and nutritional values of food items, but did not allow ranking of the nutritional values and environmental impact. Where the eligibility of the models remained uncertain, authors were contacted for additional information, which resulted in the identification of two additional[25,26] and one revised SFPM.[27] Only ten SFPMs met all inclusion criteria and were included in our analysis (figure 1).

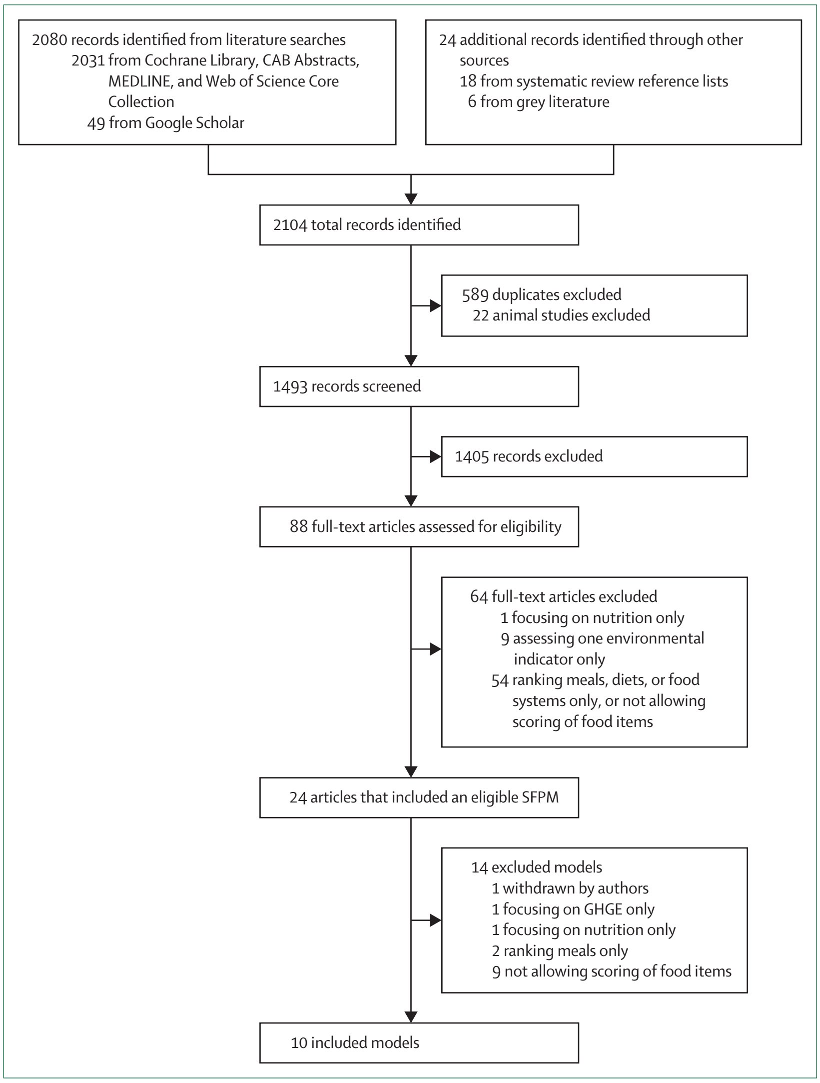

Figure 1: **Flow diagram for the selection of publications on sustainable food profiling models**
CAB=Centre for Agriculture and Bioscences. GHGE=greenhouse gas emissions. SFPM=sustainable food profiling models.

Characteristics of included models

All ten models examined multiple aspects of the environmental impact of food products (figure 2). Six of these also took into account the nutritional dimension of food products;[25–27, 29,30,33] two others accounted for economic factors;[29,30] and one model accounted for the social and energy efficiency of food products.[29] Seven of the SFPMs have been published by research institutes,[25,26,28–31,35] and the other three by companies.[33,34,36] Models were developed in Switzerland (n=3[28,32,34]), Germany (n=1[27]), France (n=2[29,30]), and the USA (n=4[25,26,32,33]).

Components and scope of the SFPMs

A total of 18 different environmental impact factors were identified across all models. The most common were greenhouse gas emissions (n=10), water use (n=8), and land use (n=6). The specific lifecycle assessment indicators of destruction of habitats, biotic resource use, and biomass removal on biotic natural resources were only accounted for in two models that specifically considered aquaculture and fishery food products.[25,29] The nutritional values assessed in the models included both nutrients whose consumption should be limited, such as sodium and sugars, and nutrients whose consumption should be encouraged, such as vitamins (figure 2).

The system boundaries set for assessing the environmental impact factors of foods included the so-called cradle-to-grave (n=2[28,30]), cradle-to-farm-gate (n=4[25,26,29,36]), and cradle-to-consumer, also referred to as farm-to-fork (n=3[27,31,34]). One model allows the user to choose the system boundaries and build a lifecycle intended for the individual use.[33] The comprehensive cradle-to-grave boundary includes the stages of production, transport, retail, consumption, and disposal, whereas

		Model name										
		Menu sustainability index[28]	Dietary environmental index[25]	SusDISH-LEH[27]	Avadi[29]	Masset[30]	Leach[31]	CONE-LCA[26]	Eaternity score[32]	Food carbon scope[33]	Beelong Eco-Score[34]	% of SFPMs fulfilling criterion
Factors of environmental impact	Greenhouse gas emission	■	■	■	■	■	■	■	■	■	■	100%
	Land use*	■	■	■	■				■		■	60%
	Biodiversity loss	■		■							■	30%
	Water use†	■	■	■	■		■		■	■	■	80%
	Eutrophication	■				■						20%
	Acidification					■						10%
	Other‡	■		■	■	■	■	■		■	■	80%
Nutritional indicators	Protein		■	■		■			■			40%
	Fibre		■	■	■	■		■	■			50%
	Vitamins§		■	■	■	■			■			50%
	Minerals¶		■	■	■	■		■	■			60%
	Unsaturated fat			■	■	■		■	■			50%
	Saturated fat		■	■		■		■	■			50%
	Sugar		■			■						20%
	Sodium		■	■		■		■	■			50%
	Energy			■	■				■			30%
System boundary	Cradle-to-farm gate		■		■			■	■			40%
	Cradle-to-consumer			■			■				■	30%
	Cradle-to-grave	■				■						20%
	Adjustable									■		10%
Reference value	Mass basis (in g, kg, or tonne)		■	■	■		■		■	■		60%
	Serving size	■						■	■		■	40%
	Energy basis (in kcal)					■	■					20%
	Per kg of protein						■					10%

Figure 2: **Overview of components and scope of each included SFPM**

Shading indicates that the model applies the components. For nutrional indications, light green indicates nutrients of which consumption should be encouraged and light red indicates nutrients of which consumption should be limited. CONE-LCA=Combined Nutritional and Environmental Life Cycle Assessment. SFPM=sustainable food profiling model. SusDISH-LEH=Sustainable Dishes *Lebensmitteleinzelhandel*. *Including deforestation. †Including water stress and water scarcity. ‡Including use of mineral primary resources, energy, pesticides, and biotic resources; biomass removal on biotic natural resources at the species and ecosystem level; photochemical oxidant formation; particulate matter formation; human toxicity; ecotoxicity; radioactive and non-radioactive waste; fish stocks depletion. §Including vitamins A, B1, B2, B3, B5, B6, B7, B9, B12, C, D, E, and K. ¶Including calcium, iron, magnesium, potassium, copper, manganese, zinc, fluoride, and phosphorus.

cradle-to-farm-gate is limited to agricultural and aquacultural production. The cradle-to-consumer provides information about the food supply chain and excludes consumer actions, thus representing the most comprehensive boundary to label food products.[25]

The reference amount from which the score was calculated varied widely, with the majority calculating the environmental impact on a mass basis (eg, per 100 g) rather than on an energy basis (eg, per 100 kcal). One approach compiled impact values per kg of product from the literature and then calculated each footprint per 1000 kcal and per kg of protein, introducing a third type of reference value.[31] Masset and colleagues[30] combined and compared different reference amounts by analysing the relationship between the environmental (per 100 g and per kg), economic (per 100 kcal and per kg), and nutritional impact (per 100 g for nutrients to promote and per 100 kcal for nutrients to limit) and affirmed that the choice of the reference amount has a decisive role for the outcome.

Although most included models presented separate scoring systems for the nutritional quality and the environmental impact of food products, some combined them into one score (figure 3). In general, two approaches were taken to combine assessments: either the environmental impact and nutritional impact were calculated separately and then combined, or nutritional impact was incorporated as the functional unit in lifecycle assessment or coupled with environmental impact assessment. The Dietary Environmental Index applies the first approach by calculating the ratio of the nutrient density score to the environmental impact score.[25]

		Model name										
		Menu sustainability index[28]	Dietary environmental index[25]	SusDISH-LEH[27]	Avadi[29]	Masset[30]	Leach[31]	CONE-LCA[26]	Eaternity score[32]	Food carbon scope[33]	Beelong Eco-Score[34]	% of SFPMs fulfilling criterion
Type of score	Point rating system*			■	■	■	■	■	■	NA		60%
	Traffic lighting†							■			■	20%
	Percentile rating	■	■	■	■							40%
	% of daily value rating‡						■					10%
Scoring system§	Combined (environment and nutrition)		■			■		■		NA		30%
	Single (environment)	■	■	■	■		■		■		■	70%
	Single (nutrition)		■	■	■	■			■			50%
Threshold values¶	Relative ranking (nutrition)					■				NA		10%
	Relative ranking (environment)	■	■	■	■	■		■	■			70%
	Absolute ranking (nutrition)		■	■	■			■	■			50%
	Absolute ranking (environment)						■				■	20%
Food rank	Food category-specific		■		■		■	■		NA		40%
	Across the board	■	■	■		■	■		■		■	70%

***Figure 3:* Overview of the scoring system of each included SFPM**

CONE-LCA=Combined Nutritional and Environmental Life Cycle Assessment. NA=corresponding data not available. SFPM=sustainable food profiling model. SusDISH-LEH=Sustainable Dishes *Lebensmitteleinzelhandel*. *Including star ratings. †Colours (green, yellow, and red) indicating the performance of a food product. ‡Applied to daily nutritional reference values in use at the national or international levels. §Indicating if a score combines nutritional and environmental impact values. ¶Absolute threshold values are derived from scientifically or politically set guidelines, whereas relative threshold values are set in comparison to the performance among other food products.

The approach of incorporating nutritional impact as the functional unit in lifecycle assessment or coupled with environmental impact assessment is used by the Combined Nutritional and Environmental Life Cycle Assessment framework, by assessing the nutritional and environmental impact in parallel and linking them to endpoint damages on human health (expressed as disability-adjusted life-years). Having both the environmental and nutritional assessment of food items in disability-adjusted live-years allows for the addition of nutritional assessment into a lifecycle impact assessment framework.[37]

One SFPM included economic impact as a third dimension of sustainability by assigning a single score of 0–3 for the nutritional, environmental, and economic impact of food items. As a consequence, fruit juices and vegetable oils received the maximum score, whereas most fruit and vegetables were penalised because of a high price per 100 kcal.[30] One approach assessing and ranking six dimensions of sustainability (environmental, ecological, economic, social, nutritional, and energetic efficiency) with an unweighted multicriterion set thus leaves the possibility of prioritising the dimensions to the decision maker.[29]

The derivation of threshold values to classify food products as sustainable was done differently for the nutritional and environmental impact factors (figure 3) and is detailed in the appendix (p 20). The ranking of nutritional values of various food products was done in accordance with national or international daily reference values: WHO (n=1[27]), German Society of Nutrition (n=2[27,36]), US Food and Drug Administration (n=2[25,29]), and FoodDrinkEurope Guideline Daily Amounts (n=1[29]). In the absence of established recommendations for the ranking of the environmental impact of food items, seven of the ten included SFPMs allow a relative rather than absolute ranking. For these models, environmental impact factors are scored against a comparison of various food products and classified in percentiles, ranking from high environmental to low environmental impact.[25–28,30,32] In comparison, the daily reference value approach determines the percentage of the consumer's total daily carbon, water, and nitrogen footprint, and sets the respective food product's footprint in relation to it.[31] The Ecological Scarcity Method, used in two SFPMs, included weighting environmental indicators on the basis of national environmental policy objectives.[27,28] The unit termed eco-points reflects the present environmental situation and distance to achieving the currently existing policy targets. Generally, the Ecological Scarcity Method applies domestic conditions as a benchmark for environmental pollution in foreign countries. If ecosystems in foreign countries are, however, substantially more affected by agricultural practices (eg, cultivation of almonds in water-scarce regions), differentiated ecofactors are used. The processes of food production are first weighted according to a regional tolerance level and then standardised to domestic conditions. For example, the differentiated eco-factor weights the consumption of 1 L of water for the cultivation of tomatoes in Morocco that are exported to Switzerland as if 1000 L of water were consumed in Switzerland.[38]

In terms of model replicability, although no code for replicating the analysis described in the publications was provided, we collected a large number of inventory databases, detailed methodology, and equations that together provide enough information to replicate some models. Seven models were scored as replicable, indicating a clearly explained method with provided equations (n=4[25,26,29,30]) or a clearly described method with a link to databases used (n=3[28,31,36]). Three models were identified as probably not replicable on the basis of the publicly available information, although all of them are available for purchase[27,33,34] (appendix p 22).

Discussion

We set out an overview of existing SFPMs, their characteristics and components, and algorithms to calculate and rank the environmental and nutritional impact of food products to ultimately assist public health professionals in adapting or developing a model to inform food labelling schemes.

A total of ten SFPMs, with a broad range of methodological approaches, met our inclusion criteria (appendix pp 16–21). We identified a total of 18 environmental indicators, which allows a comprehensive analysis, but raises questions of transferability and entails some complexity when applying the model to different geographical contexts and ecosystems. Although the indicator of greenhouse gas emissions causes global problems, other environmental impact factors have a strong source–cause relationship and a different effect on ecosystems, which need to be considered in the model.[11] For example, water use for crop production is leading to higher water scarcity in arid regions than in regions rich in groundwater. To balance environmental impact factors between global and regional scales, differentiated eco-factors for water and land use can be used.[38] The scope of the gathered environmental indicators focused on agricultural food production; only two models presented indicators appropriate for fishery products.[29,34] Globally, aquaculture is the fastest growing food production sector and affects planetary health by driving biodiversity loss and releasing anti-microbial veterinary medicines into the environment, which contributes to an increasing antibiotic resistance of bacteria that are pathogenic to humans.[39] For that reason, we recommend further efforts that integrate seafood lifecycle inventory data in SFPMs in a way that accounts for the variation in the environmental impact factors of different fish production systems, to allow consumers to make informed choices regarding fishery products. We also identified a total of 29 nutrititional indicators used by the six models that took health impact into account. These included both nutrients to avoid (eg, sugar and sodium) and nutrients the consumption of which should be encouraged (eg, vitamins and minerals). A detailed overview on the controversies of components and methods of nutrient profile models can be accessed in a systematic review by Labonté and colleagues[23] that identified 78 nutrient profile models.

Research into consumer use of food labelling schemes has consistently found that for labelling information to be useful, the same or similar format with the same underlying criteria should be used across all foods.[40] For SFPMs, algorithms should be transparent in terms of system boundaries, reference amounts, weighting across indicators, and the derivation of threshold values for classification.

The developers of SFPMs proposed different system boundaries for the lifecycle assessment of food products. Substantial environmental impacts associated with the food supply chain are mainly attributed to agricultural production; therefore, the cradle-to-consumer boundary provides appropriate information for the intended use of labelling food products.[25] Transport accounts for only 6%, manufacturing for 4%, packaging for 5%, and retail for 3% of the total share of greenhouse gas emissions in a food product lifecycle.[41] However, not accounting for these factors would underestimate the impact of foods that are transported across long distances (especially by aeroplane), are highly processed, or require refrigeration or freezing.[42]

The advantages and disadvantages of reference amounts on which the score is calculated hold an important role for the result[43] and are detailed elsewhere.[19] We found that some models advocated the measurement of environmental impact on an energy basis because products considered as healthy tend to perform worse when regarded on a mass basis instead of per energy unit (ie, kcal).[43] By contrast, some authors propose labelling sustainable food on a 100 g basis because doing so would be consistent with the mandatory existing nutrition labels in the EU and would therefore be easier to append.[30]

Whether to choose a multicomponent or combined score is relevant for ranking across dimensions and between the environmental dimension because impact factors can vary for the same food product, indicating that one product might appear favourable in terms of one environmental indicator but be less sustainable for other indicators (appendix pp 23–24). Whether ranking is carried out between specific food product categories or across all food products should take into account the intended consumer objective.[31] With the aim of reducing the overall environmental impact of a diet, an absolute comparison across all food products is suitable, whereas relative ranking is more appropriate for comparing the relative performance among products in a food category.[31] The relative ranking is particularly valuable for food categories that generally do not perform well in terms of environmental and health impact (eg, cheese) because the consumer is allowed to choose the best option in this particular category. Further work is required to find if and when ranking between or among food product categories is more effective in reaching target consumers and how can these approaches be combined.

To extend on nutrient profiling, as previously described, it is necessary to understand the benefits and drawbacks of combining the environmental and nutritional impact into one score. By having two different indexes, distinguishing between food products that are environment-friendly but nutritionally unbalanced and vice versa becomes possible. The aggregation into one score can introduce a bias towards underestimating or overestimating the healthfulness and environmental performance of food products and becomes even more complicated when economic dimensions of sustainability are added.[30] However, the choice of the reference unit (eg, per 100 g or 100 kcal) and whether the nutritional evaluation is incorporated as a functional unit in lifecycle assessment or assessed separately has an effect on the strength of the correlation between the environmental and nutritional impact.[26,30]

Regardless of the different methods to calculate a sustainability score, much needs to be decided for the translation of the results into an appropriate and consumer-friendly front-of-pack label. The included SFPMs proposed different food label designs, with combined and multicomponent scores (appendix pp 23–24). One score was designed to visually align with the established Nutri-Score, thus allowing the consumer to better understand the results.[44] Another SFPM presents the scoring in a smartphone application that allows consumers to scan the barcode, compare food products, and choose more environment-friendly and healthy options.[27] We did not assess which type of label is most effective at shifting behaviour towards healthy and sustainable outcomes because such an assessment would be outside the scope of this systematic review and warrants further investigation.

In terms of limitations, we understand from contacting researchers that some SFPMs were planned or under development while our review was underway. Given the increasing interest in sustainable food profiling and food labelling and the extensive time and resources required to assess their eligibility and extract the data, keeping a systematic review ultimately up to date is a difficult task. Although SFPMs that have been published or that we became aware of after the last eligibility assessment in September, 2020, are not included in this systematic review, we are confident that we retrieved the most relevant models to date. The extensive searches of both the peer-reviewed and grey literature and the detailed and constant eligibility check with the study authors represent a strength of this work.

At the abstract and full-text screening stage, we observed and excluded models that accounted for one environmental indicator, but those approaches can be combined to create food labelling schemes, as shown by Leach and colleagues.[31] Furthermore, about half of the excluded models were not considered because they were designed for the assessment of meals or diets and therefore beyond the scope of this systematic review, which was to identify models that can be used to inform individual food labels. However, we would like to point out that models scoring meals are an important tool to guide consumers to make informed choices in restaurants or canteens. They could further serve the purpose of labelling convenience food products and thus hold an essential role in informing product reformulation and marketing restrictions as proposed under the European Commission's Farm to Fork Strategy.[13]

As we were explicitly searching for ranking methods or cutoff values to assign environmental and nutritional values to food products, we excluded databases. However, in the absence of standardised reference values for environmental indicators, we found that sustainability ranking is often done on a relative scale. In case of percentile ranking, being aware of the range of products in which the food is ranked is important. To reduce a risk of bias towards underestimating or overestimating the environmental performance, this kind of percentile ranking could be applied to the evolving amount of comprehensive and international lifecycle inventory databases[45,46] that deliver transparent and coherent environmental data for a wide range of products. Our list of excluded models and studies will be a useful tool for anyone interested in identifying and learning more about lifecycle inventory databases and models designed for assessing diets or meals (appendix pp 9–14).

In terms of a potential geographical bias, with the exception of the model for fishery products in Peru,[29] all included models have been developed in the EU or USA. However, the included models are built upon the largest existing lifecycle inventory databases (appendix p 21) with spatially explicit impact estimates, and therefore compile the environmental impact of food products produced and consumed in different parts of the world. Furthermore, the Combined Nutritional and Environmental Life Cycle Assessment is based on the IMPACT World+ lifecycle impact assessment, which uses the world as the default region.[46] Although all models were initially designed for a particular geographical context, they could be adapted for other countries after applying the model framework to regional databases and possibly adjusting the evaluation scale. The Ecological Scarcity Method, which serves as the basis for the Menu Sustainability Index[28] and Sustainable Dishes *Lebensmitteleinzelhandel* models,[35] is based on a universal basic principle, but the evaluation standard is determined on the basis of national environmental policy objectives. The process of adaptation requires legally defined environmental goals for the concerned country, and information about the current situation of emissions and resource consumption.[38]

With the aim of creating comparable and consistent international SFPMs, future work should focus on developing reference values or a framework on how these reference values could be estimated on the basis of national contexts to classify food items as having a low or high environmental impact. Thresholds can be politically or scientifically dependent. Recent advances in politically dependent thresholds include the development of the Ecological Scarcity Method for the EU, in 2019, which reflects the present environmental situation in the EU and the distance to current EU policy targets.[47] On scientifically dependent thresholds, the EAT–*Lancet* Commission has proposed a scientific target for greenhouse gas emissions from food production to achieve healthy and sustainable diets within planetary boundaries.[6] The percent daily value method could be applied to an average or optimum sustainable diet to provide the consumer with a sense of the magnitude of a food item within the scope of a healthy and sustainable diet.[31]

We identified the absence of a suitable quality assessment tool for systematic reviews of food profiling models. Therefore, we constructed a scoring system to assess the included models against the replicability criteria and introduced replicability as a key quality metric, which is a novel approach and facilitates the comparison of models.

This systematic review identifies existing SFPMs and further discusses the benefits and limitations of different methods and components. In this manner, it provides public health, environmental, and policy makers the ability to choose or construct a tool to promote sustainable public health nutrition, increases public awareness of the environmental impact of food products, and supports food producers in reformulating their products to be more sustainable. Given the importance of a standardised method to assess and label the sustainability of food products in a globalised and international food retail sector,[15] additional research is needed to identify how the identified approaches could form the foundation of a cross-national SFPM to produce consistent and comparable data for all agents along the food value chain.

Contributors

All authors contributed to study protocol development, discussed and reviewed the data extraction process, revised and provided comments to draft versions, and read and approved the final version for submission. NR developed the search strategy and did peer-reviewed literature searches. ACB searched grey literature, conducted the data extraction, and developed the first draft of the manuscript. ACB and JR screened the publications. HR contacted study authors for additional information where required. MC developed the replicability criteria.

Declaration of interests

We declare no competing interests.

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