Science of the Total Environment 789 (2021) 147936

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Towards a Water-Energy-Food (WEF) nexus index: A review of nutrient profile models as a fundamental pillar of food and nutrition security

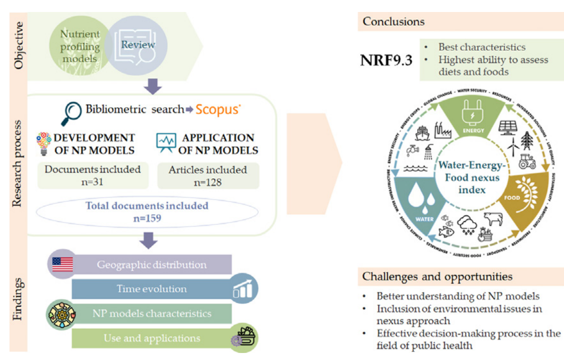
Ana Fernández-Ríos [a], Jara Laso [a], Cristina Campos [a], Israel Ruiz-Salmón [a], Daniel Hoehn [a], Jorge Cristóbal [a], Laura Batlle-Bayer [b], Alba Bala [b], Pere Fullana-i-Palmer [b], Rita Puig [c], Rubén Aldaco [a,*], María Margallo [a]

[a] Department of Chemical and Biomolecular Engineering, University of Cantabria, Av. de Los Castros s/n, 39005 Santander, Spain
[b] UNESCO Chair in Life Cycle and Climate Change ESCI-UPF, Pg. Pujades 1, 08003 Barcelona, Spain
[c] Department of Computer Science and Industrial Engineering, University of Lleida (UdL), Pla de la Massa, 8, 08700 Igualada, Spain

HIGHLIGHTS

- Literature regarding nutrient profiling models is reviewed.
- Mapping, time evolution, and characterization of the studies is assessed.
- NRF9.3. is the best model to be used in a Water-Energy-Food nexus index.
- NP models are a useful tool for an effective decision-making process.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 April 2021
Received in revised form 17 May 2021
Accepted 18 May 2021
Available online 21 May 2021

Editor: Damia Barcelo

Keywords:
Diet quality
Nutrition value
Food analysis
Dietary assessment
Public health
Sustainability

ABSTRACT

The Water-Energy-Food (WEF) nexus approach should be promoted as a tool for sustainable management of resources through the interconnection of these three fundamental pillars. Particularly, food security must ensure healthy and balanced diets for everyone, but selecting individual indicators to assess all slants covered by this element is not an easy task. Hence, the objective of this paper is two-fold, to review nutrient profiling (NP) models that allow to categorize foods and evaluate diets based on their nutritional quality, and to choose the most appropriate model to be used within a WEF nexus index. To address this issue, a total of 159 documents were assessed, appraising the geographic distribution, and time evolution of the publications, as well as the characteristics and potential applications of the NP systems. The review concludes that the NRF9.3. model is the most liable option to be used in a WEF nexus index, presenting the best characteristics by means of the definition of scores and thresholds, and the use of an 'across-the-board' criteria and a reference quantity of 100 kcal, alongside offering higher ability to assess diets and foods than the other competitive model (HEI) through the evaluation of nutrients to encourage instead of foods. A secondary outcome of the review is the identification of the NP models as a useful tool to enable institutions with information to establish policies in the field of public health and facilitating the decision-making process according to the current healthy claims.

* Corresponding author.
E-mail address: aldacor@unican.es (R. Aldaco).

https://doi.org/10.1016/j.scitotenv.2021.147936
0048-9697/

Contents

1. Introduction

According to world projections, in the next decades fresh water, energy, and food demand will significantly increase in virtue of the pressure exerted by the growth and mobility of the population, economic development, international trade, urbanization, diversification of diets, cultural and technological changes, and climate change (FAO, 2014a). Due to the close relationship between these challenges, meeting demand will be restricted by competitive needs for limited resources in many parts of the world (Zhang et al., 2018). Water is indispensable for life but also for the production, distribution, and use of energy, being approximately 15% of the world's total water withdrawal destined to this purpose (Chang et al., 2016). Conversely, the water-energy nexus is plain in the energy consumption for water services, including water withdrawal, treatment, distribution, and wastewater management (Cai et al., 2018). Food systems currently consume 30% of the world's available energy, of which the primary production of crops, live-stock, and fisheries account for 6.6% (Chang et al., 2016). On the other hand, the water-food nexus mainly refers to the water footprint of agricultural and animal products, and food and beverage production, being 70% of the fresh water withdrawn from aquifers, streams, and lakes (FAO, 2021a). Given the importance of the water-energy, food-energy, and water-food nexus, these three components should be combined to broaden the standpoint. Therefore, the Water-Energy-Food (WEF) nexus is currently being promoted and developed in response to this challenge, providing a tool to improve these elements through an interdisciplinary approach that recognizes the inherent synergies and trade-offs involved in the management of these resources (Proctor et al., 2021). The WEF nexus perspective entails different aspects concerning food, water, and energy securities, being the 'access', 'utilization', and 'availability' those that stand out, constituting the core elements of WEF. The 'availability' element concerns the distribution, processing or production of food, energy conversion and renewable and non-renewable sources, and water abstraction, distribution, or treatment, whereas the 'access' involves purchase, self-production, and food, energy, and water aid. Finally, the 'utilization' entails the consumption of food, addressing the nutritional value, and energy and water use (Bizikova et al., 2013). However, managing WEF resources simultaneously and meeting multiple objectives is a difficult task since conflicting criteria and goals can occur in the decision-making process (Kumar et al., 2017). Therefore, this issue must be resolved without compromising any other sector or causing the least amount of damage possible (Purwanto et al., 2021), for which composite indexes have been demanded to reduce the complexity of this work (Kalbar et al., 2016). According to the Stockholm Environment Institute (2011), to implement the nexus framework three action fields should be considered; i) society, by means of accelerating the access and integrating the bottom of the social pyramid, and developing and implementing technologies and policies, ii) economy, through the thought 'creating more with less', and investing capital, and iii) environment, investing to sustain ecosystems services (SEI, 2011). The outputs and opportunities offered by the use of a WEF approach are directly related to improving WEF security, while contributing to support the transition to a green economy. The latter aims to achieve resource use efficiency, a more resilient and productive environment, and greater policy coherence, facilitating the decision-making process and assessing consequences and planning for investments, policies, and actions (Albrecht et al., 2018). Fig. 1 displays the WEF nexus framework describing the action fields, the promoters, the linkages between the nexus elements, and the outputs.

In recent years, there has been a call to move from 'nexus thinking' to 'nexus action' (Simpson and Jewitt, 2019), giving rise in 2020 to the *WEF nexus indicator*, developed by Simpson et al. (2021). This composite index comprises the three resources sectors by means of individual indicators addressing the 'access' and 'availability' sub-pillars. Another example is the *Water-Energy-Food Nexus Tool 2.0.*, created by Daher and Mohtar (2015), which assesses different scenarios based on the WEF nexus characteristics, in addition to environmental and financial aspects of the area under study. Likewise, the Sustainable Development Solutions Network; Bertelsmann Stiftung (2017) gave rise the *Sustainable Development Goals index* (SDG index), which compiles a wide range of indicators for measuring the degree of sustainability in several countries (Diaz-Sarachaga et al., 2018), based on the 17 SDGs that involve social (including WEF security), economic, and environmental problems (United Nations Statistics Division, 2021). Finally, the FAO (2014b) designed the *nexus rapid appraisal*, which combines WEF, capital and labor indicators, and provides a stepwise process to address policymaking and intervention in a nexus manner. These first three indexes (*WEF nexus indicator, WEF nexus tool 2.0.* and *SDG index*) evaluate single indicators regarding the 'access' and 'availability' sub-pillars, such as prevalence of undernourishment (%), prevalence of obesity among adult population (%), cereal yield (t/ha), or percentage of food products grown in open agriculture conditions (%), among others. On the contrary, the last index (*nexus rapid appraisal*) assesses indicators for specific nexus issues linking energy-water, water-food, and energy-food. For instance, the availability of freshwater resources for agriculture, water desalination for irrigation, land use, or energy for irrigation are some indicators entailed by the *nexus rapid appraisal*. Nevertheless, although the creation of these models and indicators supposes a great advance in the field, several aspects referred to WEF security are generally ignored, causing 'gaps' in the systems. It is worth noting the lack of analysis of some sub-pillars, especially in the food element, which mainly entails food security but not nutritional. Although in some cases nutritional factors are considered, the 'utilization' element is

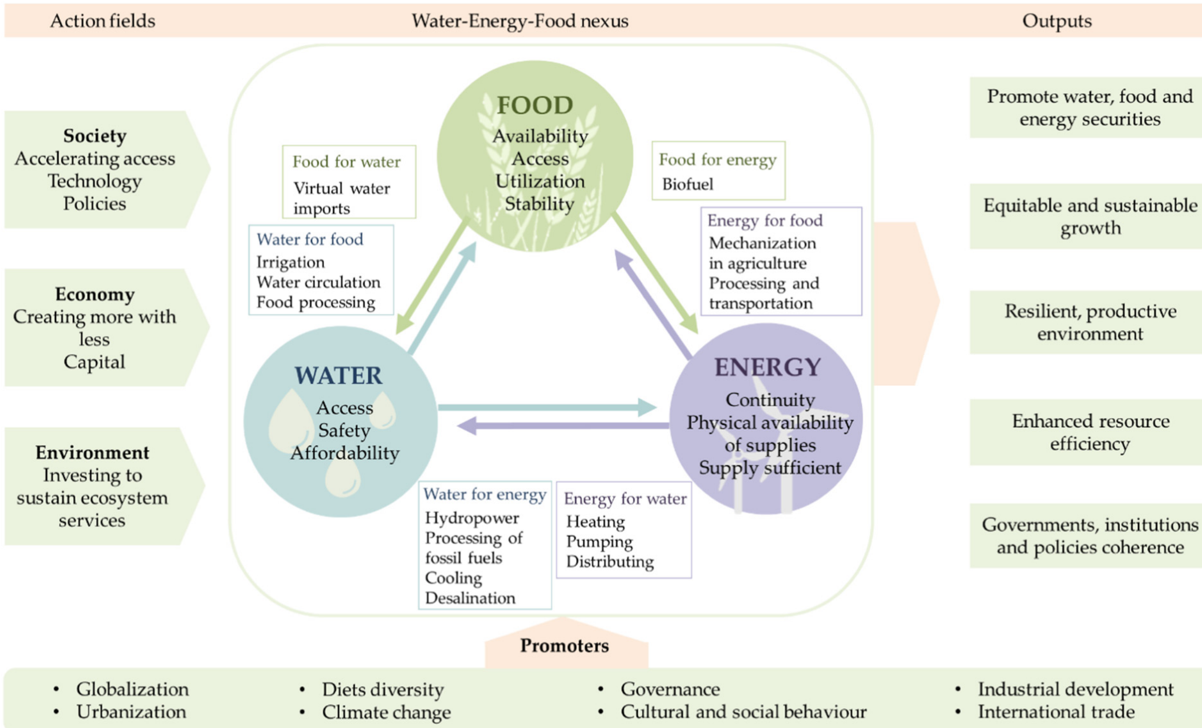


Fig. 1. The Water-Energy-Food nexus framework (Bizikova et al., 2013; Mohtar and Daher, 2012; SEI, 2011).

quite poorly integrated in the models. In addition, they also do it in a fairly generic way, evaluating only energy or protein intake adequacy, while balanced diets are only achieved by the appropriate combination of nutrients. For this reason, this paper is focused on the 'utilization' subpillar of the food element of WEF nexus, which is directly related to nutrition security that considers the nutritional value of food that guarantees personal well-being.

In this framework, given that meeting nutrient needs is essential in order to be free from malnutrition and achieve food and nutrition security (Bose et al., 2019), the concept of nutrient profiling (NP) was introduced. NP is defined as the science of categorizing foods according to their nutritional composition (Rayner et al., 2004) and it has become the basis for regulating nutrition and health claims in the European Union (Drewnowski et al., 2009). NP is being used as part of a range of nutritional policy applications worldwide and the number of different nutritional indicators, named NP models or NP systems, have been rapidly expanded over the years (Sacks et al., 2011). Although these NP systems characterize food options, they represent a way to improve dietary choices, and hence overall dietary patterns, through a variety of applications in the field of public health (WHO, 2010). Moreover, these indicators now have several uses including supporting consumers to make healthier food choices by means of the food labeling systems, to determine which food products should be available for sale, to establish the regulation of health or nutrition claims, and to implement restriction of food marketing (Santos et al., 2021).

In this context, the objective of the paper is to make a revision of different NP models with the aim of finding the most appropriate to be used as an indicator to evaluate the nutritional aspect of a WEF nexus index. The need to carry out this revision is based on filling a 'gap' found in the food pillar of the previous developed nexus indicators. Hence, the review of the articles leads to the identification of the most appropriate system, which provides a contribution and an advance for the development of future complex WEF nexus indicators, saving the process of studying and selecting the optimum model. Furthermore, as a secondary objective, this systematic review intends to contribute to a better understanding of the NP models through the compilation and comparison of the systems' characteristics, facilitating their comprehension for any person or organization that required their use, such as health institutions of policymakers when proposing policies and measures according to the current healthy claims.

2. Materials and methods

2.1. Literature search strategy and inclusion criteria

This review tries to address the most relevant studies in the field of nutritional indicators that allow to carry out the NP of different foods and diets. Both original articles and reports in English were included in the study. The definition of the scope made it possible to discard those documents that do not fit with the subject of the review; studies belonging to the medical, nursing, or veterinary area, i.e., based on the analysis of diets or foods to cure or to reduce the risk of specific diseases (cancer, diabetes, cardiovascular problems, etc.) were excluded. Likewise, articles focused on the use of indicators that evaluate a single nutrient were not included as they do not provide a global vision of the overall quality of foods. Finally, studies evaluating other factors that affect diets quality (e.g. household water, hygiene conditions, etc.) or develop other methods to assess the NP (e.g. spectroscopy) were discarded.

The bibliographic search was carried out in two stages in order to make a classification of the documents based on their objective; firstly, the NP models were identified and, subsequently, the state of implementation of these systems was analyzed. Data collection was performed by a literature search of articles available in Scopus and websites of national and international governmental agencies (e.g. World Health Organization (WHO)). A scheme of all steps performed to the identification and classification of the studies is available in Fig. 2. Initially, documents focused on the development of novel nutritional indicators were assessed. On the one hand, reports of international agencies, such as the WHO, or national agencies, like AFSSA (The Agence Française de sécurité sanitaire des aliments), were analyzed. A total of 10 reports were included in the review, being six of

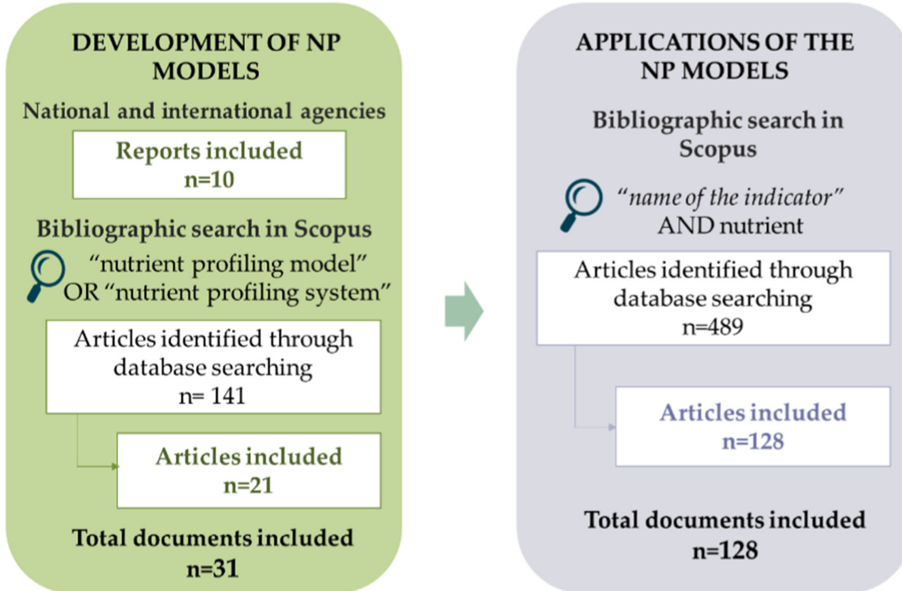


Fig. 2. Diagram of the steps to follow in the bibliographic search.

them referring to models of different wide regions (e.g. Europe, Africa, etc.) and the remaining four of specific countries. On the other hand, articles which include the terms "*nutrient profiling system*" or "*nutrient profiling model*" in the abstract, keywords or title were assessed. A total of 141 documents were found in the Scopus database, but only 21 of them were included in the review. The remaining articles were excluded as they were not within the defined scope, had other objective, or addressed different topics, e.g., the relation of diseases and diets quality. Briefly, a total of 31 documents regarding the development of novel NP models were appraised, of which 43 NP systems were identified. The second step was to make a search of each model in the database of Scopus in order to know their impact on literature, i.e., its state of implementation and applications. In this case, the terms "*nutrient*" and "*name of the indicator*", previously identified in the 31 documents, were introduced for each index. Therefore, considering the 43 NP models, a total of 489 articles were found, of which 128 were included in the review, and 361 dismissed, mainly because they analyzed the relationship between diet quality or nutrient density and the risk of suffering or worsening diseases or health problems such as diabetes, obesity or iron deficiency, among others.

2.2. Analysis of study findings

Each document included in the review was appraised independently in order to identify its objective, as well as its methodology and conclusions. The following characteristics of the NP models were analyzed: nutrients that it evaluates, type of model, model criteria, and reference quantity. According to Scarborough et al. (2006), these characteristics, illustrated in Fig. 3, should be considered when developing this type of indicators. The first stage is the selection of the nutritional criteria, i.e., the nutrients considered by the NP model. There are two types of nutrients: i) disqualifying or negative nutrients, or nutrients to limit, that have negative impact on health when consuming in excess (Drewnowski, 2017), and ii) qualifying or positive nutrients and foods, or nutrients and foods to encourage, identified as beneficial for health when consumed in appropriate amounts (Lobstein and Davies, 2008).

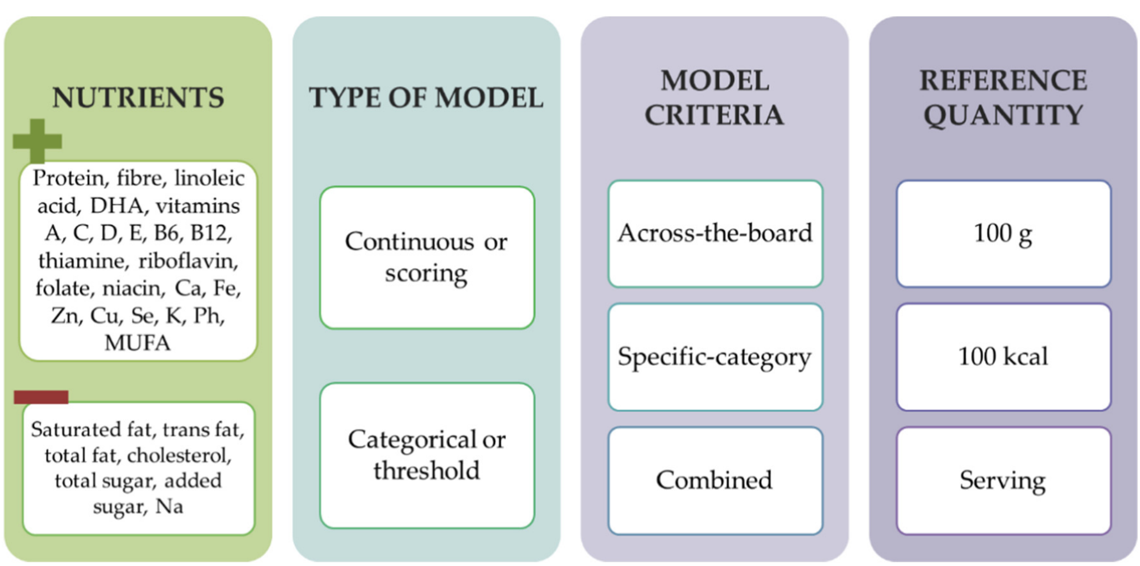


Fig. 3. Points to consider in the selection of the NP models.

The second point to consider is the type of model. There are indicators based on: i) the definition of thresholds for each nutrient; for a qualifying nutrient is based on the minimum content in a food, whereas for a disqualifying nutrient is based on the maximum, and they operate by considering whether or not a food has a nutrient content higher or lower than a specified threshold, and ii) the definition of an overall score, which combines the punctuation of each nutrient to obtain a global score and it is used to rank foods (Santos et al., 2021). In third place, models can present different criteria when evaluating the quality of a food. The 'across-the-board' models use the same criteria to evaluate foods that are naturally different, allowing health institutions to encourage people to switch to healthier foods categories, for instance, from sweets to vegetables. The 'specific-category' systems distinguish foods into categories and have specific criteria for each nutrient (FINUT, 2017), influencing the change in the consumption patterns of foods of the same category, for example, from sweetened drinks to 100% orange juice (WHO, 2010). Finally, the scores can be expressed per different reference quantities. The most commonly ones are 100 g of edible food, 100 kcal or serving. 'Per 100 g' is the reference most applied, probably because it is the base used in food composition tables and in the required format for nutrition labeling in the EU. However, a food that is high in a nutrient on a 'per 100 g' basis may supply little of that nutrient to the diet because it is eaten in small amounts and/or infrequently. On the other hand, using 'per 100 kcal' and 'per serving' references involve knowing the amount of food that people commonly eat, which it is quite variable depending on the consumer (Scarborough et al., 2006).

In relation to the documents addressing the application of the NP systems, the type of model, and the application in which it is used were the most remarkable information. Other characteristics, such as if they concerned economic, environmental, or well-being aspects were also considered due to the importance they could have when deciding the best NP model to apply in an indicator with a nexus approach.

3. Results and discussion

A total of 159 documents were reviewed; 31 regarding the development of NP models (21 articles and 10 reports), and 128 addressing their implementation and application. In this section, the analysis of the studies is presented: i) the geographical distribution, ii) the time evolution, iii) the characterization of the NP models, iv) the state of implementation and potential applications of the systems, and v) the main findings and decision.

3.1. Mapping of the studies

Fig. 4 shows the location of the research institutions involved in the evaluated studies. Only original articles were included in Fig. 4, whereas institution reports were dismissed as most of them refer to broad regions, not specific countries. These regions encompass large areas such as continents, so that most of the world has a more or less complex NP system to analyze their specific diets or local foods. The icons represent the countries in which NP models were developed, along with the number of studies conducted, while the colored areas illustrate the territories in which documents regarding their application were carried out. Studies addressing the development of NP models were focused on North America (59%) and Europe (41%). Most of the articles were conducted by institutions from the same country, whereas six had international collaboration and involved researchers from two or three regions. In addition, 16 publications were developed and published in different states of the United States. This makes evident the great importance of this scientific issue in the region, either because of the country's level of development or because of the interest in this field. In a European context, France ranked first in the spread of NP systems, carrying out or collaborating in 4 publications. Switzerland (3 studies), the Netherlands (3), and Italy (1) also had an important role in the creation of nutritional indicators.

In relation to publications about the use of NP models, almost all regions contributed, to a greater or lesser extent, to their development. 34 studies were carried out in an international context, but most of the articles were conducted by authors of the same geographic area. United States represented the region with the largest impact in this field, with 60 studies, following the trend previously mentioned of a large number of NP models proposed in this territory. In second place was situated France (25 articles) followed by United Kingdom (15) and Canada (12), which produced significant research. With lower contribution, Asian countries, largely driven by Japan, which participated in 7 studies, and followed by Iran (4), China (1), Lebanon (1), Republic of Turkey (1) and Pakistan (1), had a role in the study of nutrition quality; however, considering the large population of Asia, its global influence was very low. The European ranking (ignoring UK and France) was led by

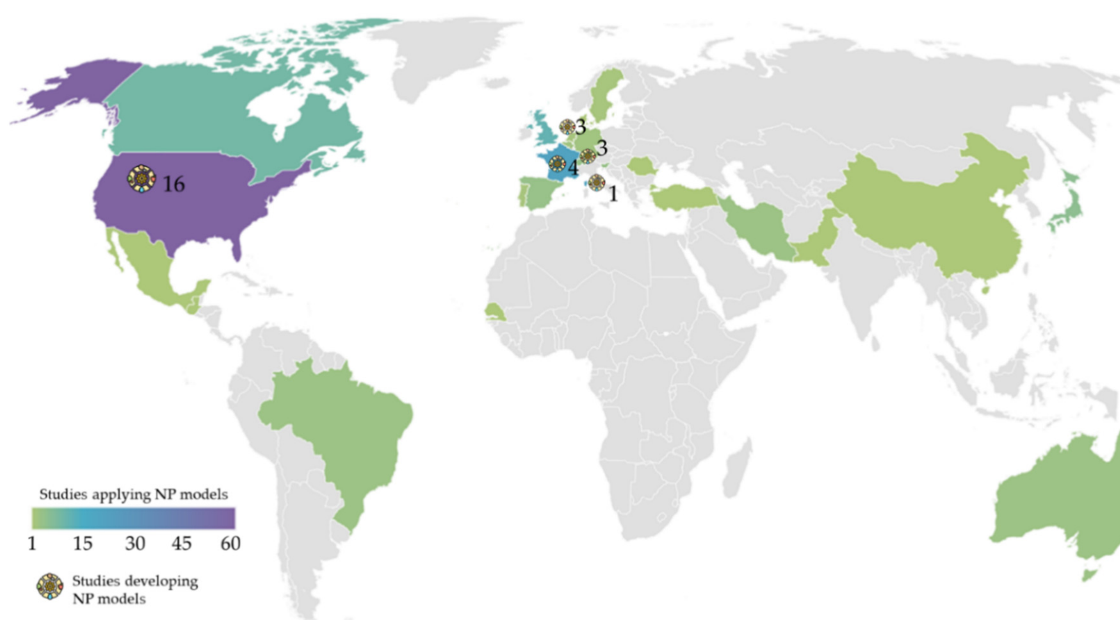


Fig. 4. Geographical distribution of the studies included in the review. Reports were excluded from the figure. Icons represent the countries where NP models were developed and colored territories where application studies were carried out.

Switzerland (5), Spain (5) and Slovenia (5). Finally, Oceania participated in 7 studies (4 in Australia and 3 in New Zealand), Central and South America in 5 (conducted in Brazil and Guatemala) and Africa in 1 (Senegal). In these last two regions, hardly any articles on this topic have been developed. Although, in general, the European, Asian, North American, and Oceanic regions have been significantly reducing the prevalence of undernourishment over the years due to their level of development, as well as to the policy frameworks that address all the pillars of food security (FAO, 2017), in Africa and South America this issue has worsened. In Africa, due to global economic conditions, conflicts, and climate-related disasters, food security has aggravated, causing a quarter of the population being undernourished (FAO, 2018). With respect to South America, despite being one of the regions with the highest production and exportation of food products, the central problem concerning hunger is consequence of the problems faced by the poorest members of society in gaining access to that food (FAO, 2021b). Hence, the absence of documents regarding nutritional indicators in these regions may be caused by their generally poor research of food and nutrition security, as well as of the lack of resources. It is also possible that scientific studies were carried out regarding the use of other nutritional indicators not covered by this review in these geographical areas. Unfortunately, this lack of bibliography into developing countries can be hardly minimized by national governmental and supra-governmental reports. Only the WHO and the PAHO (Pan American Health Organization) developed NP models destined to be applied in the African (WHO, 2019) and American (PAHO and WHO, 2016) regions, respectively. However, this is not a great advance because in developing countries the nutritional variable of the WEF nexus is generally measured by means of malnutrition and food insecurity, mainly based on the SDGs indicators (FAO, 2019). For instance, in Africa the SDG indicators 2.4.1. relative to the proportion of sustainable agricultural production per unit area (cereal productivity) and 2.1.2. regarding the prevalence of moderate or severe food insecurity in the population (self-sufficiency) are the most important references of food security (Nhamo et al., 2020). On the other hand, in South America and the Caribbean the prevalence of undernourishment, corresponding to the SDG indicator 2.1.1 is the highest considered (Mahlknecht et al., 2020). The policy and practical consequences of the lack of information related to the nexus in developing countries, specifically concerned to the nutritional variable, could entail wrong public policies, as well as the promotion of worst governance plans and the inefficiency in the use of natural resources. Consequently, it is imperative include the nexus approach, whose interrelationships are diverse, complex, and intensive in developing countries.

3.2. Time evolution of the studies

Fig. 5 illustrates the temporary evolution of the studies. The drawing of the bottom side of the figure represents the year when different NP models were developed, along with the number of studies, whereas the line illustrates the number of publications addressing their application. On the one hand, the development of NP systems had not increased over the years, since in most cases 1 or 2 articles were published per year on this topic. However, it is possible to observe a greater perseverance and periodicity in the publications in the last 7 years, while prior to this period, no articles were developed in 3 years (period 2010–2012). On the other hand, an increasing number of publications addressing the implementation of the nutritional indicators was observed. Initially, the increase in publications was moderate (period 2006–2012), but from this last year the growth was highly significant. This evidence the greater concern and awareness about food issues, related to food safety or health problems (such as overweight) linked to poor food consumption and unbalanced diets, among other reasons. In addition, from 2010, the WHO began to highlight the importance of food security and nutrition issues, as well as to develop their own nutritional indicators, with the intention of improving public health. Given that approximately around this year the number of publications started to rise, it can be suggested that these initiatives influenced the development of several studies worldwide.

3.3. NP models' characterization

Table 1 summarizes the main characteristics of the NP models included in the review. The nutrients to encourage and to limit were quite similar in almost all the models even though their number varied significantly depending on the study. Nevertheless, several systems were adjustable, i.e., the number of ingredients to assess can be increased or decreased based on the application. Generally, the selection of the nutrients for the inclusion in the indexes was based on the regulatory frameworks and dietary guidance (Drewnowski et al., 2009). Healthy foods were based on their content of protein and fiber, as well as micronutrients such as vitamins A and C, calcium, and iron (Food and Drug Administration, 2021). Moreover, the selection of other micronutrients was based on the high prevalence of vitamins and mineral deficiencies at a global level (Bailey et al., 2015) and their serious adverse health effects due to, in part, inadequate dietary intake of certain nutrients (Jomaa et al., 2016). On the other hand, the strong relationships observed between diet-related diseases and the high consumption of fats, sugars, and sodium arose the need of limiting

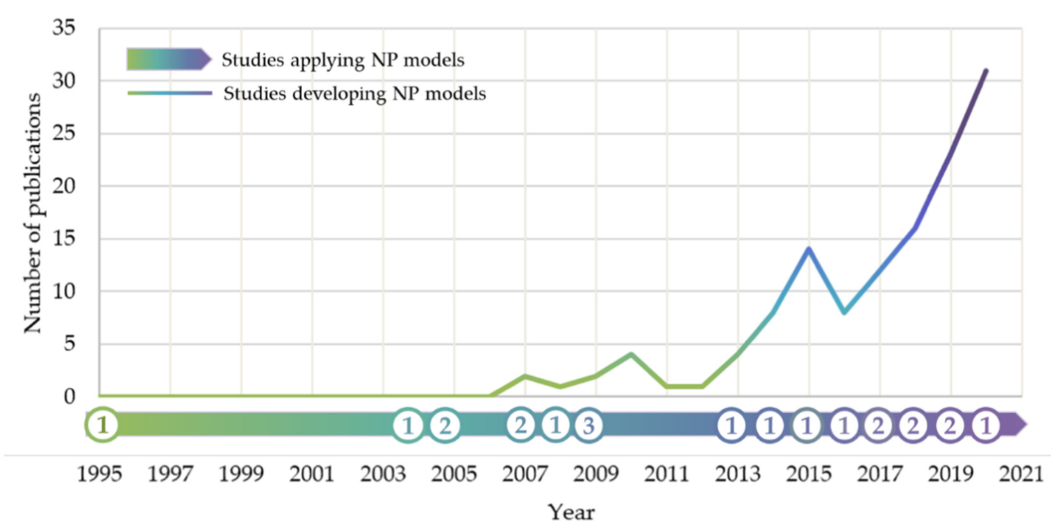


Fig. 5. Temporary distribution of the studies included in the review. Reports were excluded from the figure. Temporary evolution drawing represents when the articles addressing the development of NP models were published, along with the number of documents, and the graphic's line the time evolution of publications regarding their application.

Table 1
Summary of the main characteristics of the NP models included in the review. SFA: Saturated fatty acids; FA: Fatty acids; ALA: Alpha linoleic acid; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids.

NP model	Nutrients to encourage	Foods to encourage	Nutrients to limit	Type of model	Model criteria	Reference amount	Ref.
WHO EURO (World Health Organization Europe)	–	–	Total fat, added sugar, total sugar, non-sugar sweeteners, SFA, industrially produced trans FA, energy and salt or Na	Threshold	Specific-category	100 g or 100 mL	[1]
WHO Eastern Mediterranean region (World Health Organization Eastern Mediterranean region)							[2]
PAHO (Pan American Health Organization)							[3]
WHO Western Pacific region (World Health Organization Western Pacific region)							[4]
WHO South-East Asia region (World Health Organization South-East Asia region)							[5]
WHO African region (World Health Organization African region)							[6]
SAIN (Score d'adéquation individuel aux recommandations nutritionnelles)	Protein, fiber, vitamins A, C, D, E, B6, B12, B3, Ca, Fe, ALA, Mg, K, Zn, thiamine, riboflavin, folate, DHA, Cu, I and Se	–	–	Scoring	Across-the-board	100 kcal	[7]
LIM (Limited Nutrient Score)	–	–	SFA, added sugar and Na	Scoring	Across-the-board	100 g	
UK FSA/Ofcom (Food Standard Agency/Office of Communications)	Protein and fiber	Fruit, vegetables and nuts	Total sugar, SFA and Na	Scoring	Combined	100 g	[8]
FSANZ or NPSC (Food Standards Australia New Zealand)	Protein and fiber	Fruit, vegetable, nuts and legume	SFA, energy, sugar and Na	Threshold and scoring	Specific-category	100 g or 100 mL	[9]
HCST (Health Canadian Surveillance Tool)	–	–	Fats, sugar and Na	Threshold	Specific-category	100 g	[10]
RRR (Ratio of Recommended to Restricted food)	Protein, fiber, vitamins A, C, Ca, and Fe	–	Energy, sugar, SFA, cholesterol, and Na	Threshold and scoring	Across-the-board	Serving	[11]
HEI (Healthy Eating Index)	–	Total grains, vegetables and fruits, milk, meat and amount of variety	Total fat, SFA, cholesterol, and Na	Scoring and threshold	Across-the-board	Serving	[12]
HEI-2005 (Healthy Eating Index-2005)	–	Total fruit, vegetables and grains, whole fruit, dark green and orange vegetables and legumes, whole grains, milk, meat and beans, and oils	SFA, Na, calories from solid fats, alcoholic beverages, and added sugars	Scoring and threshold	Across-the-board	1000 kcal	[13]
HEI-2010 (Healthy Eating Index-2010)	FA, and seafood and plant protein	Total fruit, vegetables and protein foods, whole fruit, greens and beans, whole grains, and dairy	Refined grains, Na, and empty calories	Scoring and threshold	Across-the-board	1000 cal	[14]
HEI-2015 (Healthy Eating Index-2015)	FA, and seafood and plant protein	Total fruit, vegetables and protein foods, whole fruit, greens and beans, whole grains, and dairy	Refined grains, Na, added sugars, and SFA	Scoring and threshold	Across-the-board	1000 kcal	[15]
NNR (Naturally Nutrient Rich)	Protein, MUFA, vitamins A, C, D, E, B12, folate, thiamine, riboflavin, Fe, Zn, K, and Ca	–	–	Scoring	Across-the-board	100 g	[16]
NAS (Nutrient Adequacy Score)	Protein, fiber, vitamins A, C, D, E, B6, B12, thiamine, riboflavin, folate, niacin, pantothenic acid, Ca, Fe, and Mg.	–	–	Scoring	Across-the-board	100 g	[17]
NDS (Nutrient Density Score)	Protein, fiber, vitamins A, C, D, E, B6, B12, thiamine, riboflavin, folate, niacin, pantothenic acid, Ca, Fe, and Mg.	–	–	Scoring	Across-the-board	100 kcal	
NDS (Modified Nutrient Density Score)	Protein, fiber, ALA, linolenic acid, DHA, vitamins A, C, D, E, B6, B12, thiamine, riboflavin, folates, niacin, Ca, Fe, Zn, Mg, Cu, Se, K, and Ph	–	–	Scoring	Across-the-board	2000 kcal	[18]

(continued on next page)

Table 1 (*continued*)

NP model	Nutrients to encourage	Foods to encourage	Nutrients to limit	Type of model	Model criteria	Reference amount	Ref.
ONQI (Overall Nutritional Quality Index)	Fiber, folate, vitamins A, C, D, E, B6, B12, K, Ca, Zn, omega-3, bioflavonoids, carotenoids, Mg, and Fe	–	SFA, trans fat, Na, sugar, and cholesterol	Scoring	Across-the-board	100 kcal	[19]
Nutrimap	Carbohydrates, lipids, MUFA, PUFA, fiber, folic acid, vitamins C, D, E, Ca, Fe, and Mg	–	Fat, SFA, sugar, and Na	Scoring	Specific-category	100 kcal	[20]
SENS ($SAIN_{SENS}$+ LIM_{SENS}) (Simplified Nutrition Labelling System)	Vitamin C, ALA, MUFA, protein, and fiber	Fruit and vegetables	SFA, free sugar, and Na	Scoring	Specific-category	100 kcal $SAIN_{SENS}$ and 100 g LIM_{SENS}	[21]
NRF9.3. (Nutrient Rich Food 9.3)	Protein, fiber, vitamins A, C, E Ca, Fe, Mg, and K		SFA, added sugar, and Na	Scoring and threshold	Across-the-board	100 kcal	[22]
NR6 (Nutrient Rich 6)	Protein, fiber, vitamins A, C, Ca, and Fe		–	Scoring	Across-the-board	100 kcal	
NR9 (Nutrient Rich 9)	Protein, fiber, vitamins A, C, E, Ca, Fe, Mg, and K		–	Scoring	Across-the-board	100 kcal	
NR11 (Nutrient Rich 11)	Protein, fiber, vitamins A, C, E, B12, Ca, Fe, Mg, Zn, and K		–	Scoring	Across-the-board	100 kcal	
LIMt (Limited Nutrients Score)	–		Total fat, total sugar, and Na	Threshold	Across-the-board	100 kcal	
NRF11.3. (Nutrient Rich Food 11.3.)	Protein, fiber, vitamins A, C, E, B12, Ca, Fe, Zn, Mg, and K		SFA, added sugar, and Na	Scoring and threshold	Across-the-board	100 kcal	[23]
NRF15.3. (Nutrient Rich Food 15.3.)	Protein, fiber, MUFA, vitamins A, C, D, E, B12, thiamine, riboflavin, folate, Ca, Fe, Zn, and K		SFA, added sugar, and Na	Scoring and threshold	Across-the-board	100 kcal	
NRD9.3. (Nutrient Rich Diet 9.3.)	Protein, fiber, vitamins A, C, E Ca, Fe, Mg, and K		SFA, added sugar, and Na	Scoring and threshold	Across-the-board	100 g	[24]
TNR9 (Total Nutrient Rich 9)	Protein, fiber, vitamins A, C, E Ca, Fe, Mg, and K	–	–	Scoring	Across-the-board	100 g	[24]
TLIM3 (Total Limiting Score 3)	–	–	SFA, added sugar, and Na	Threshold	Across-the-board	100 g	
QI (Qualifying Index)	Energy, fiber, protein, water, linolenic acid, ALA, choline, vitamins A, B12, B6, C, D, E, K, folate, niacin, pantothenic acid, riboflavin, thiamine, Ca, Cu, Fe Mg, Mn, P, K, Se, and Zn	–	–	Scoring	Specific-category	100 kcal	[25]
DI (Disqualifying Index)	–	–	Total fats, SFA, cholesterol, trans fats, Na, total sugar, and energy	Threshold	Specific-category	100 kcal	
NBS (Nutrient Balance Score)	The same as QI	–	–	Scoring	Specific-category	100 kcal	
qCaln (Quantity of kilocalories for nutrition)	Fiber, vitamins A, D, C, Ca, Fe, and Zn	–	SFA, total sugar, Na	Scoring	Specific-category	100 g	[26]
SNRF (Sustainable Nutrient Rich Food)	EFA, protein, and fiber	–	Saturated fat, total sugar, and Na	Scoring	Across-the-board	100 g	[27]
DNS (Disqualifying Nutrient Score)	–	–	Sugar, cholesterol, SFA, and total fat	Threshold	Across-the-board	100 kcal	[28]
E-NR*n* (Elderly-Nutrient Rich 8)	Protein, fiber, vitamin D, folate, Ca, K, Mg, PUFA, I, Zn, Vit C, Vit E, Se, Vit B12, Vit B6 and Fe	–	–	Scoring	Across-the-board	100 g	[29]
E-NRF*n*.3. (Elderly-Nutrient Rich Food *n*.3.)	Protein, fiber, vitamin D, folate, Ca, K, Mg, PUFA, I, Zn, Vit C, Vit E, Se, Vit B12, Vit B6 and Fe	–	SFA, Na, and disaccharides	Scoring and threshold	Across-the-board	100 g	[29]
NNA (Nestlé Nutrition Algorithm)	Carbohydrates, protein, total fat, fiber, K, Ca, Mg, Fe, folate, vitamins A, D, E, and C	–	Added sugars, SFA, energy and Na	Scoring	Specific-category	Reference intake	[30]
NRFh (Nutrient Rich Food Hybrid Score)	Protein, fiber, MUFA, PUFA, vitamins A, B12, C, D, E, folate, Ca, Fe, K, and Mg	Total dairy, whole grain, nuts and seed, fruits and vegetables	Total SFA, Na, and added sugars	Scoring and threshold	Across-the-board	100 kcal	[31]

References: [1] WHO (2015); [2] WHO (2017a); [3] PAHO and WHO (2016); [4] WHO (2016); [5] WHO (2017b); [6] WHO (2019); [7] AFSSA (2008); [8] Department of Health (2011); [9] FSANZ (2016); [10] Health Canada (2014); [11] Scheidt and Daniel (2004); [12] Kennedy et al. (1995); [13] Guenther et al. (2008); [14] Guenther et al. (2013); [15] Krebs-Smith et al. (2018); [16] Drewnowski (2005); [17] Darmon et al. (2005); [18] Maillot et al. (2007); [19] Katz et al. (2009); [20] Labouze et al. (2007); [21] Darmon et al. (2018); [22] Drewnowski (2009); [23] Fulgoni et al. (2009); [24] Van Kernebeek et al. (2014); [25] Fern et al. (2015); [26] Jomaa et al. (2016); [27] Van Dooren et al. (2017); [28] Chaudhary et al. (2018a); [29] Berendsen et al. (2019); [30] Mainardi et al. (2019); [31] Drewnowski and Fulgoni (2020).

these nutrients (Huth et al., 2013). With regard to the type of model, generally, the same trend was observed in the systems. Those indicators that evaluate only nutrients to limit defined thresholds to restrict the maximum intake of negative ingredients according to public health organizations. On the contrary, in those models assessing just nutrients to encourage, the definition of an overall score was used, since they usually depend on the recommendary nutrient intakes (not minimum intake), providing a more flexible model. Consequently, composite indicators were usually combined models. Regarding the model criteria, most of the NP systems presented an 'across-the-board' criteria, evaluating different food categories by the same criteria and ranking foods according to their score. However, most of the schemes developed by public organizations and food industry to label foods tended to use 'specific-category' criteria (e.g. WHO models) with the aim of making a classification of food as 'healthy' or 'healthier'. Finally, the reference amounts of 100 g and 100 kcal were the most used. Nevertheless, other basis such as 'per serving' or 'per 2000 kcal' were applied in a number of studies, since for consumers these references provide an easier measure to interpret when dealing with intake per plate or per day (instead of per energy or 100 g, which represents a very small amount of food).

In regard to the NP systems, in 2015 the WHO started to develop the WHO models, which should be applied in different territories according to the regions; Europe (WHO EURO), Eastern Mediterranean, American (PAHO), Western Pacific, South East Asia, and Africa. These models were designed as a tool for the design and implementation of various regulatory strategies related to the prevention and control of obesity or overweight, through the restriction in the marketing of unhealthy foods to children, the regulation of school food environment, and the use of front-of-package warning labels, among other measures (PAHO and WHO, 2016). Despite the fact that these indicators were apparently the same, the models discriminated different food categories according to the dietary patterns of each region, e.g., in the Western Pacific region the coconut juices constitute a food category whereas in the European territory this beverage is not assessed (WHO, 2016). In addition, some institutions developed NP models at a national level. AFFSA proposed the 'Score d'adéquation individuel aux recommandations nutritionnelles' (SAIN) and the Limited Nutrients Score (LIM) models in France, which evaluated both nutrients to encourage and nutrients to limit, respectively (involving from 5 to 23 positive ingredients depending on the application). These scores were initially created to analyze the relationship between nutritional quality and the cost of the food (AFSSA, 2008). Similarly, the UK Food Standard Agency/Office of Communications (FSA/Ofcom) model was developed by the FSA as a tool to help to identify 'less healthy' foods and drinks that must be subjected to restrictions during children's television programming (Department of Health, 2011). Finally, the Nutrient Profile Scoring Criteria (NPSC) model, proposed by the Food Standard Australia New Zealand (FSANZ) organization, determined whether a food is suitable to make a health claim based on its nutrient profile (FSANZ, 2016). However, unlike the SAIN and LIM system, which only analyzed nutrients, these scores evaluated foods to encourage (nuts, fruits and vegetables) considering them as an important part of healthy and balanced diets. In last place regarding institutional reports, Health Canada organization proposed the Health Canadian Surveillance Tool (HCST) system, which was quite similar to the LIM indicator, with the aim of making a classification of foods in the Canadian Nutrient File according to Canada's Food Guide (Government of Canada, 2021), which is the standard reference food composition database for reporting the amount of nutrients in foods that people commonly consume in this region (Health Canada, 2014).

Regarding other NP models assessed, several similarities could be observed among them. The Healthy Eating Index (HEI) was one of the first NP models, developed in 1995 by Kennedy et al. (1995). This indicator was proposed to monitor changes in consumption patterns, as well as serve as a useful tool for nutrition education and health promotion (Kennedy et al., 1995). Four versions of the HEI were created over the years, modifying the number of ingredients according to the changes in diets and health claims. The first two versions, HEI original and HEI-2005, evaluated 6 and 12 foods to encourage, and 3 and 6 nutrients to limit, respectively, being ingredients modifications based on the recommendations to ensure adequate nutrient intake (Guenther et al., 2008). Nevertheless, a large number of changes were incorporated from the HEI-2005 to the HEI-2010 version. In the latter, alcoholic beverages, added sugar, and calories from solid fats were renamed as empty calories, a more concise term used to convey this concept to consumers. In addition, positive foods were changed according to the 2010 Dietary Guidelines (U.S. Department of Agriculture, 2010), adding 3 nutrients to encourage. This fact allowed the flexibility in food choices, e.g., including protein in vegan diets without consuming meat or fish (Guenther et al., 2013). Finally, the last version (HEI-2015) was quite similar to the previous one, being the removal of the empty calories' component and the addition of added sugars and SFA (saturated fatty acids) the only change (Krebs-Smith et al., 2018).

In a different vein, the Naturally Nutrient Rich (NNR) index, firstly developed by Drewnowski (2005), could be considered as the starting point or basis of another type of NP models. This system was born to plan meals and diets, offering a dietary guidance according to health claims. It consisted of a nutrients-to-calories ratio based on the mean percentage daily values for 14 positive nutrients (Drewnowski, 2005). The same year, Darmon et al. (2005) developed a very similar indicator so-called the Nutrient Adequacy Score (NAS), which evaluated a total of 16 positive nutrients. In addition, the Nutrient Density Score (NDS) indicator was proposed to obtain a measure per 100 kcal (instead of per 100 g), considering the energy density of the foods (Darmon et al., 2005). Along the same lines, Maillot et al. (2007) suggested an expanded and modified version of the previous NDS, which assessed a total of 23 nutrients, and presented the score per daily energy intake (8 MJ or 2000 kcal). This author also evaluated the LIM system (AFSSA, 2008), providing the score per 1.4 kg, instead of per 100 g, which is approximately the daily intake of food, to avoid favoring energy-dense foods (Maillot et al., 2007). Afterwards, the first composite indicator of this type was developed. Drewnowski (2009) putted forward the Nutrient Rich (NR) models, a modified version of the NNR (Drewnowski, 2005) and the NDS (Darmon et al., 2005; Maillot et al., 2007) indicators. The NR*n* systems could evaluate a large range of nutrients (*n*), from 5 to 15; however, the NR6, NR9 and NR11 stood out. Furthermore, this author proposed another variation of the LIM score, providing the punctuation per 100 kcal of energy instead of per mass amount. The difference between the NR9 and LIM scores gave rise to the Nutrient Rich Food 9.3. (NRF9.3.) model, which combined both nutrients to encourage and nutrients to limit (Drewnowski, 2009), as well as the NRF11.3 and NRF 15.3, proposed by Fulgoni et al. (2009), which considered a larger number of positive ingredients (11 and 15, respectively). On the other hand, Van Kernebeek et al. (2014) adapted the NRF9.3. model to the Nutrient Rich Diet 9.3. (NRD9.3.) in order to quantify the composite nutritional quality of a diet. For this purpose, the LIM and the NR9 indexes (Drewnowski, 2009) were recalled as Total Limiting 3 (TLIM3) and Total Rich Nutrient 9 (TRN9) respectively, expressed per mass unit. The difference of these sub-scores gave rise to the NRD9.3. system (Van Kernebeek et al., 2014). Van Dooren et al. (2017) also suggested a variant of the NRF9.3., the Sustainable Nutrient Rich Food (SNRF), that in fact is the NRF3.3. (Drewnowski, 2009) as it consisted of 3 macronutrients to encourage and 3 to limit. Given that this author tried to identify synergies between climate impact and nutritional characteristics, the index was based on nutrients that correlate strongly with greenhouse gases emissions (GHGE) and included macronutrients from the Health Score (Van Dooren et al., 2017). The elderly-NR (*E*-NR) and elderly-NRF (E-NRF) indicators were putted forward by Berendsen et al. (2019). The novelty of these models was the use of daily values of nutrients for older adults, with the aim of measuring the quality of the diets in this group of people. Finally, the last model known was the Nutrient Rich Food hybrid (NRFh), developed by

Drewnowski and Fulgoni (2020). This system, derived from the NRF9.3., included a group of food to encourage (total dairy, whole grain, nuts and seeds, total fruits, and total vegetables), so it would be best aligned with the HEI-2015 diet quality scores (Drewnowski and Fulgoni, 2020).

Additionally, a number of NP models, that do not use the NNR as a basis, were developed by several authors. In 2004, the Ratio of Recommended to Restricted food (RRR) composite index was designed to provide consumers with a summary of food label information to guide healthful, single-item food selections (Scheidt and Daniel, 2004). On the other hand, the Overall Nutritional Quality Index (ONQI), developed by Katz et al. (2009), incorporated both nutrition and epidemiology science, which allowed to address the link between nutrients and health outcomes. Like the RRR, this was a composite index that assessed 16 positive nutrients and 6 ingredients to limit (Katz et al., 2009). The Nutrimap model aimed to position food items in relation to other within the same food category, paying special attention to flexibility and pragmatism (Labouze et al., 2007), whereas the SENS was designed to be operational for simplified nutrition labelling in line with the European regulation on food information to consumers (Darmon et al., 2018). The latter is a modified version of the SAIN and LIM scores (AFSSA, 2008), presenting the unique advantage of not combining the two indicators that account for qualifying and disqualifying nutrients, respectively, which made it more operational (Darmon et al., 2018). Fern et al. (2015) also proposed two quantitative indices- the qualifying index (QI) and the disqualifying index (DI)- for assessing overall nutrition quality when combining foods and meals. This author analyzed the largest number of nutrients to encourage, and defined QI as the ratio of each nutrient contained in 2000 kcal of a given food relative to its dietary reference intake value. Similarly, the DI considered the maximal reference values. Furthermore, Fern et al. (2015) created the Nutrient Balanced (NB) score, which was an indicator of the extent to which a food, meal or diet can satisfy the daily requirements for all qualifying nutrients. Based on the previous DI, Chaudhary et al. (2018a) calculated a new model called Disqualifying Nutrient Score (DNS), by comparing the total daily intake of four public health-sensitive food nutrients (sugar, cholesterol, SFA and total fat) with their maximal reference values. Jomaa et al. (2016) suggested the qCaln (quantity of Calories for nutrition) model, defending that the quality of the food is mainly determined by the amount and distribution of key micronutrients. Because of this, the author selected a total of 10 micronutrients for the inclusion in the algorithm; 7 positive ingredients and 3 negative ones. Finally, the Nestlé Nutrition Algorithm (NNA) was a nutrient-based model that assessed the nutrient density of dietary patterns, which aimed to award maximum scores to consumption patterns that kept both energy and nutrients within the healthy range (Mainardi et al., 2019).

3.4. NP models' applications

In this section, the impact of the use and application of NP models in other literature were interpreted through the analysis of 128 articles. A summary of the main characteristics of the documents is reported in Table A.1. of the Supplementary Materials. Six main applications were identified: i) evaluation of diets quality, ii) evaluation of foods quality, iii) analysis of the impact of specific food categories in overall diet quality, iv) study of the relation between diet quality and environmental issues, v) study of the relation between diet quality and food costs, and vi) assessment of the relation between diet quality and well-being and health (Fig. 6). In relation to the NP models, the HEI, particularly the HEI-2010 and HEI-2015, and the NRFn.3., concretely the NRF9.3. version, were mostly applied by the authors, being used in more than 50% of the total documents (Fig. 7).

Analyzing in detail the articles, NP models were used 65 times for the analysis of diets quality. In this classification, studies regarding the evaluation of typical households' diets of several geographic areas, such as Spanish (Esteve-Llorens et al., 2020a), Portuguese (Esteve-Llorens et al., 2020b), Iranian (Ebrahimi et al., 2020), Canadian (Jessri et al., 2017), German (Peltner and Thiele, 2017), American (Thompson et al., 2020) diets, among others, as well as specific meals or menus, like breakfast (Gibney et al., 2018), school menus (Alexis et al., 2020), fast-food menus (Kirkpatrick et al., 2013), dinners (Arlinghous et al., 2018), etc., were included. Furthermore, applications related to the analysis of diets based on the age range, such as elderly people (Tomata et al., 2019), adolescents (Hassan et al., 2017) or children (Rauber et al., 2014), and different type of diets, like vegan (Karlsen et al., 2019), vegetarian (Blaurock et al., 2021) or pesco-vegetarian (Clarys et al., 2014) were considered. The HEI model was the largest applied to this purpose, accounted 26 times, followed by the NRFn.3., applied 20 times. In second place, the quality of foods was evaluated 45 times. In this category, studies regarding the evaluation of foods from a specific category, e.g. yoghurt (García et al., 2020), cereals (Debeljak et al., 2015), potato (Wu et al., 2020), common (Hess and Slavin, 2017) and fruity (Drewnowski and Richonnet, 2020) snacks (Hess et al., 2017), deep-frying options (Bassama et al., 2015), as well as national typical foods, such as Romanian (Voinea et al., 2015), Slovenian (Kupirovic et al., 2019), or Lebanese (Issa et al., 2009) products, and different types of food choices based on their characteristics, for instance, Canadian (Franco-Arellano et al., 2019) or Australian (Kaur et al., 2016) prepackaged foods, vending machine products (Rozman et al., 2020), processed (Fardet et al., 2018), ultra-processed (Gupta et al., 2019, 2020), or unprocessed (Drewnowski et al., 2020) foods were included. In this case, the NRFn.3 was the greatly applied, adopted in eight studies. Secondly, the FSANZ was used 7 times, followed by the UK FSA/Ofcom and the SAIN, LIM models. As Fig. 6 reported, the HEI was not applied for this purpose, due to this indicator was designed to analyze diets instead of foods. The analysis of the nutritional impact of specific food consumption in the overall diet quality was accounted 31 times. These foods usually included fruit juices (Agarwal et al., 2019), vegetable juices (Francou et al., 2015), grapes (Murphy et al., 2014), pasta (Fulgoni and Bailey, 2017), red (Boehm et al., 2019) or lean (Agarwal et al., 2015) meat, raisin (Fulgoni et al., 2017), cereals (Rehm and Drewnowski, 2017), yoghurt (Cifelli et al., 2020), or rice (Della Lucia et al., 2016), among other food categories. The HEI model, followed by the NRFn.3. were the most used. In one study, other indicators, namely NNR, FSANZ and NBS were applied. With less relevance but with a significant number of applications, NP systems implementation for the analysis of the relation between diet quality and food costs was applied 15 times, while well-being, and environmental aspects reached 14 and 12 applications, respectively. Despite the fact that the main objective of some of these studies was not to establish the relationship between these elements, but rather that this purpose was defined as a secondary objective, the relevance that these aspects may have within a nexus approach has led to their consideration when analyzing the documents. Finally, a total of 14 articles were focused on other applications, e.g., comparison between models (Labonté et al., 2017), agreement of results applying different systems (Applehans et al., 2017), validation of models (Vieux et al., 2018), etc. In addition, it is worth noting the use of other indicators, not covered by this study, 10 times. These cases applied models in conjunction with the indicators already mentioned, since they were mostly FoP nutrition labelling systems. For instance, the nutri-score (Hagmann and Siegrist, 2020) or the traffic-light model (Rosentreter et al., 2013) which allow to identify by means of a color scale printed on the food package its nutritional quality.

3.5. Findings of the study and model selection

The evaluation and classification of the studies led to the identification of the HEI (2010 or 2015) and NFR9.3. indicators as the most extensively applied NP models. Taking into consideration that the main application of the systems was the analysis of the quality and identification of healthy and affordable foods and diets, these models present the

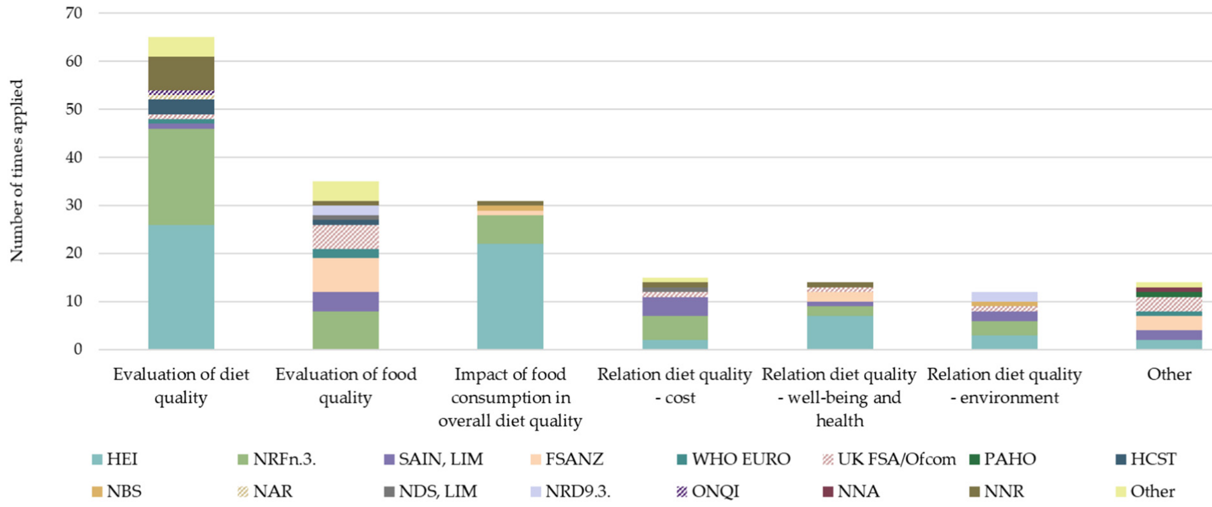


Fig. 6. Application of the NP models evaluated in the studies included in the review.

great advantage of being composite indicators, allowing to evaluate both positive and negative nutrients. Therefore, they provide a broader and more detailed perspective considering all ingredients that must be consumed to guarantee balanced diets. For that reason, they are likely to be chosen to make up and quantify the food element of a WEF nexus index. Other NP models, such as those developed by national institutions (e.g. FSANZ, UK FSA/Ofcom) had also an important impact. Nevertheless, their application was quite restricted to the geographical area in which they were develop, due to the wide diversity of diets along countries, making them less appropriate.

Firstly, it is worth noting the use of the NRF9.3. instead of other NRF*n*.3. indicators, such as NRF15.3 or NRF21.3., which evaluate a larger number of nutrients. This is due to the fact that a greater number of nutrients does not translate into a better quantification of the diets or

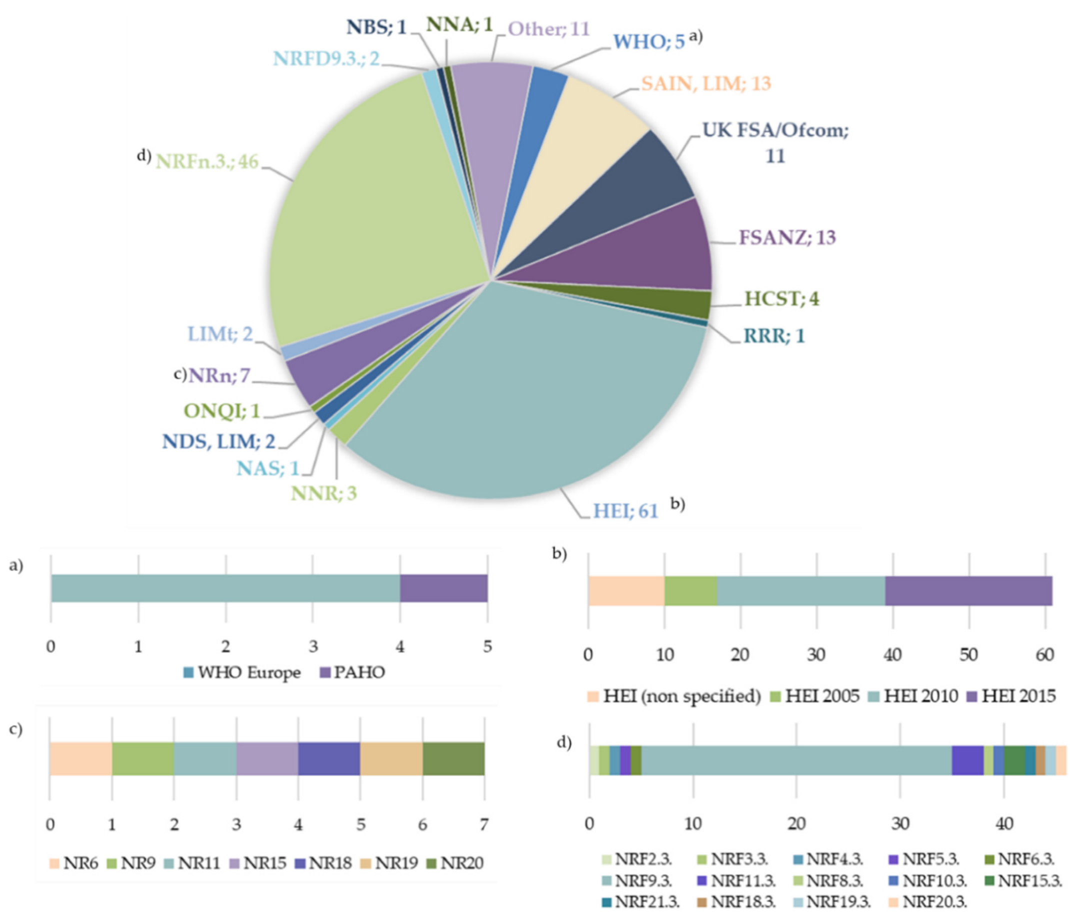


Fig. 7. State of implementation of the NP models. On the top, contribution of each model to the total; on the bottom, use of each version of the models: a) WHO, b) HEI, c) NRn, and d) NRFn.3.

foods quality (Bianchi et al., 2020). Given that the NRF9.3. considers essential macronutrients, vitamins, minerals, and the most important nutrients to limit, it presents the best characteristics and highest ability to assess diet quality. Regarding the characteristics of the HEI and NRF9.3. models, both systems present an 'across-the-board' criterion, so they are suitable for getting a global vision of the quality of different foods, helping to design more balanced diets and allowing to switch from unhealthy eats to more wholesome options. Likewise, both models are continuous and categorical, allowing to consider both maximum intakes and recommended values of the negative and positive nutrients, respectively, as well as obtaining a final score for each food enabling to rank them. However, the type of ingredients they evaluate differs significantly, and this aspect was mainly considered in making the decision. Whereas the HEI (2010 or 2015) mostly evaluates food categories, the NRF9.3. assesses nutrients. Given that the nutrient analysis is considered more accurate, since it does not discriminate any type of food or diet, for instance, vegan or vegetarian, which do not obtain protein by the consumption of fish and meat, the NRF9.3. would be more appropriate. In addition, this model provides the results per 100 kcal, which is the most standardized and appropriate measure when comparing with other indicators. Another important point to take into account is the calculation algorithm. The scoring system of HEI is based on cup or ounce equivalent for food components, so if a non-American diet is evaluated it would be necessary to prepare a cup or ounce equivalent database for each nutrient. On the contrary, applying the NRF9.3. this calculation methodology is direct, as its scoring system is based on g or mg for each food component, which are the most common and widespread units among databases related to nutritional content of foods (Murakami et al., 2020a). Finally, even though the NRF9.3. was developed as a method of ranking the nutritional quality of foods, it was found to be highly correlated to diet quality as measured through the HEI, and it can be successfully applied to individual foods, meals, menus, and the daily diet, evidencing its flexibility and adaptation (Walker et al., 2018).

On the other hand, given that the final objective of the model is to be applied in a WEF nexus indicator, it is worth focusing on the influence of economic, social and, especially, environmental aspects, which are usually considered in these indexes. In this regard, nutritional-cost (García-Herrero et al., 2019; Vázquez-Rowe et al., 2020) and nutritional-climate indicators stood out (Batlle-Bayer et al., 2021; Laso et al., 2018a; Mustafa et al., 2021). Moreover, nutrient density indexes are increasingly used as complementary functional units in life cycle assessment (LCA) studies, since expressing the environmental impact of foods in relation to the nutritional quality is a promising approach in the search for methods integrating interdisciplinary sustainability perspectives (Bianchi et al., 2020). Conversely, other authors did not consider the nutritional aspect of foods or beverages, focusing on a water-energy-climate nexus approach (Leivas et al., 2020). Hence, analyzing the influence of the environmental factor in the literature, it would be interesting to consider this element within the nexus approach, as suggested Laso et al. (2018b) and Susnik et al. (2021). Based on this, Bianchi et al. (2020) evidenced the adequacy of the NFR models to be included in the environmental analysis of food, suggesting to be suitable as complementary functional unit in comparative LCA studies across food categories. In conclusion, although both indicators, HEI and NRF9.3., present good characteristics to be implemented in a WEF nexus indicator, the NRF9.3 would be highly recommended for this purpose.

4. Conclusions

The WEF nexus approach has emerged and promoted as a tool to highlight and improve the interdependence of water, energy, and food security promoting to a better management of resources. Particularly, food security, which involve different aspects of access, availability and utilization, has turned into a heart of research in the last years, as the increasing number of studies regarding nutritional issues demonstrate. The review of the 159 documents showed that, from 2006, the increase in the development of articles related to the creation and application of NP models has been practically unstoppable, being almost exponential in the last 4 years and highlighting its importance in international institutions such as the WHO. Their coverage was largely limited to developed countries, with a large proportion of studies focusing on US located in North America, followed by territories of Europe and Oceania, which allow knowing the degree of concern and awareness about these issues in the regions. The characterization of the NP models led to similar features of the systems. The simplest models that evaluate positive nutrients considered protein, fiber, vitamins (mainly A and C), calcium and iron as essential ingredients, while the most developed ones included up to 28 ingredients. Likewise, three negative nutrients, namely fat, sugar, and sodium, were usually restricted by the models. In addition, most indicators used the same evaluation criteria for different categories of food, used both thresholds and scores, and generally considered a reference unit of 100 kcal or 100 g. By the analysis of the degree of implementation of the models, the NRF9.3. and HEI were the most widely used, especially for the quantification of the quality of diets and foods.

Summing-up, the main outcome of this review is the appropriateness of using the NRF9.3. model as indicator to represent the food pillar of a WEF nexus index, as it presents the best characteristics and ability to assess foods and diets quality. Furthermore, this state-of-art document allows to identify NP models as a useful instrument for an effective decision-making process in the field of public health as well as to assist consumers to make healthier food choices.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.147936.

Declaration of competing interest

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

Acknowledgments

The authors are grateful for the funding of the Spanish Ministry of Science and Innovation through the KAIROS-BIOCIR project (PID2019-104925RB) (AEO/FEDER, UE) and of the Interreg Atlantic Area through the NEPTUNUS project (EAPA_576/2018). Daniel Hoehn thanks the Ministry of Economy and Competitiveness of Spanish Government for their financial support via the research fellowship BES-2017-080296. Jorge Cristóbal acknowledges financial support from the Spanish Ministry of Science, Innovation and Universities through the "Beatriz Galindo" grant BEAGAL18/00035.

References

AFSSA. Setting of nutrient profiles for accessing nutrition and health claims: proposals and arguments. Report, 2008.

Agarwal, S., Fulgoni, V.L., Berg, E.P., 2015. Association of lunch meat consumption with nutrient intake, diet quality and health risk factors in US children and adults: NHANES 2007–2010. Nutr. J. 14, 128.

Agarwal, S., Fulgoni, V.L., Welland, D., 2019. Intake of 100% fruit juice is associated with improved diet quality of adults: NHANES 2013-2016 analysis. Nutrients 11 (10), 2513.

Albrecht, T.R., Crootof, A., Scott, C.A., 2018. The water-energy-food Nexus: a systematic review of methods for nexus assessment. Environ. Res. Lett. 13, 043002.

Alexis, T.D., Unruh, D., Wang, W., Dave, J.M., Miketinas, D.C., Chen, T., Moore, C.E., 2020. Implementation of a food scholarship program improves nutrient intake and dietary quality of college students. J. Am. Coll. Health, 1–8 https://doi.org/10.1080/07448481.2020.1848847.

Applehans, B.M., French, S.A., Tangney, C.C., Powell, L.S., Wang, Y., 2017. To what extent do food purchases reflect shoppers' diet quality and nutrient intake? Int. J. Beh. Nutr. 14, 46.

Arlinghous, K.R., Vollrath, K., Hernandez, D.C., Momin, S.R., O'Connor, T.M., Power, T.G., Hughes, S.O., 2018. Authoritative parent feeding style is associated with better child dietary quality at dinner among low-income minority families. Am. J. Clin. Nutr. 108, 730–736.

Bailey, R.L., West Jr., K.P., Black, R.E., 2015. The epidemiology of global micronutrient deficiencies. Ann. Nutr. Metab. 66 (2), 22–33.
Bassama, J., Achir, N., Trystram, G., Collignan, A., Bohuom, P., 2015. Deep-fat frying process induces nutritional composition diversity of fried products assessed by SAIN/LIM scores. J. Food Eng. 149, 204–213.
Batlle-Bayer, L., Bala, A., Aldaco, R., Vidal-Monés, B., Colomé, R., Fullana-i-Palmer, P., 2021. An explorative assessment of environmental and nutritional benefits of introducing low-carbon meals to Barcelona schools. Sci. Total Environ. 756, 143879.
Berendsen, A.A.M., Kramer, C.S., de Groot, L.C.P.G.M., 2019. The newly developed elderly nutrient-rich food score is a useful tool to assess nutrient density in European older adults. Front. Nutr. 6, 119.
Bianchi, M., Strid, A., Winkvist, A., Lindroos, A., Sonesson, U., Hallström, E., 2020. Systematic evaluation of nutrition indicator for use within food LCA studies. Sustainability 12, 8992.
Bizikova, L., Roy, D., Swanson, D., Venema, H.D., McCandless, M., 2013. The water-energy-food security nexus: towards a practical planning and decision-support framework for landscape investment and risk management. Report.
Blaurock, J., Kaiser, B., Stelzl, T., Weech, M., Fallaize, R., Franco, R.Z., Hwang, F., Lovegrove, J., Finglas, P.M., Gedrich, K., 2021. Dietary quality in vegetarian and omnivorous female students in Germany: a retrospective study. Int. J. Environ. Res. Public Health 18, 1888.
Boehm, R., Ver Ploeg, M., Wilde, P.E., Cash, S.B., 2019. Greenhouse gas emissions, total food spending and diet quality by share of household food spending on red meat: results from a nationally representative sample of US households. Public Health Nutr. 22 (10), 1794–1806.
Bose, I., Bladi, G., Kiess, L., de Pee, S. The, 2019. Fill the nutrient gap" analysis: an approach to strengthen nutrition situation analysis and decision making towards multisectorial policies and systems change. Matern. Child Nutr. 15, e12793.
Cai, X., Wallington, K., Shafiee-Jood, M., Marston, L., 2018. Understanding and managing the food-energy-water nexus- opportunities for water resources research. Adv. Water Resour. 111, 259–273.
Chang, Y., Li, G., Yao, Y., Zhang, L., Yu, C., 2016. Quantifying the water-energy-food nexus: current status and trends. Energies 9, 65.
Chaudhary, A., Gustafson, D., Mathys, A., 2018a. Multi-indicator sustainability assessment of global food systems. Nat. Commun. 9, 848.
Cifelli, C.J., Agarwal, S., Fulgoni, V.L., 2020. Association of yogurt consumption with nutrient intakes, nutrient adequacy, and diet quality in American children and adults. Nutrients 22, 3435.
Clarys, P., Deliens, T., Huybreehts, I., Deriemaeker, P., Vanaelst, B., De Keyzer, W., Hebbelinck, M., Mullie, P., 2014. Comparison of nutritional quality of the vegan, vegetarian, semi-vegetarian, pesco-vegetarian and omnivorous diet. Nutrients 6, 1318–1332.
Daher, B.T., Mohtar, R.H., 2015. Water-energy-food (WEF) nexus tool 2.0.: guiding integrative resource planning and decision-making. Water Int. 40, 748–771.
Darmon, N., Darmon, M., Maillot, M., Drewnowski, A., 2005. A nutrient density standard for vegetables and fruits: nutrients per calorie and nutrients per unit cost. J. Am. Diet. Assoc. 105, 1881–1887.
Darmon, N., Sondey, J., Azaïs-Braesco, V., Maillot, M., 2018. The SENS algorithm- a new nutrient profiling system for food labelling in Europe. Eur. J. Clin. Nutr. 72, 236–248.
Debeljak, K., Pravst, I., Kosmelj, K., Kac, M., 2015. "Healthier" and "less healthy" classifications according to three nutrient profiling systems relative to nutrition and health claims on food labels. Acta Aliment. 44 (4), 561–569.
Della Lucia, C.M., Rodrigues, K.C.C., Rodrigues, V.C.C., Santos, L.L.M., Cardoso, L.M., Martino, H.S.D., Franceschini, S.C.C., Pinheiro-Sant'Ana, H.M., 2016. Diet quality and adequacy of nutrients in preschool children: should rice fortified with micronutrients be included in school meals? Nutrients 8, 296.
Department of Health, 2011. Nutrient profiling technical guidance. Report.
Diaz-Sarachaga, J.M., Jato-Espino, D., Castro-Fresno, D., 2018. Is the sustainable development goals (SDG) index an adequate framework to measure the progress of the 2030 agenda? J. Sustain. Dev. 26 (6), 663–671.
Drewnowski, A., 2005. Concept of a nutritious food: toward a nutrient density score. Am. J. Clin. Nutr. 82, 721–732.
Drewnowski, A., 2009. Defining nutrient density: development and validation of the nutrient rich foods index. J. Am. Coll. Nutr. 28 (4), 421S–426S.
Drewnowski, A., 2017. Uses of nutrient profiling to address public health needs: from regulation to reformulation. PNK 76, 220–229.
Drewnowski, A., Fulgoni, V.L., 2020. New nutrient rich food nutrient density models that include nutrients and MyPlate food groups. Front. Nutr. 7, 107.
Drewnowski, A., Richonnet, C., 2020. Dairy and fruit listed as main ingredients improve NRF8.3. Nutrient density scores of children's snacks. Front. Nutr. 7, 15.
Drewnowski, A., Maillot, M., Darmon, N., 2009. Testing nutrient profile models in relation to energy density and energy cost. Eur. J. Clin. Nutr. 63, 674–683.
Drewnowski, A., Gupta, S., Darmon, N., 2020. An overlap between "Ultraprocessed" foods and the preexisting nutrient rich food index? Food Nutr. 55 (2).
Ebrahimi, S., McNaughton, S.A., Leech, R.M., Abdollahi, M., Housshiarrad, A., Livingstone, K.M., 2020. A comparison of diet quality indices in a nationally representative cross-sectional study of Iranian households. Nutr. J. 19, 132.
Esteve-Llorens, X., Martín-Gamboa, M., Irribarren, D., Moreira, M.T., Feijoo, G., González-García, S., 2020a. Efficiency assessment of diets in the Spanish regions: a multi-criteria cross-cutting approach. J. Clean. Prod. 242, 118491.
Esteve-Llorens, X., Dias, A.C., Moreira, M.T., Feijoo, G., González-García, S., 2020b. Evaluating the Portuguese diet in the pursuit of a lower carbon and healthier consumption pattern. Clim. Chang. 162, 2397–2409.
FAO. El nexo Agua-Energía-Alimentos. Un nuevo enfoque en respaldo de la seguridad alimentaria y de la agricultura sostenible. Report, 2014a.
FAO, 2014b. Walking the Nexus talk: assessing the water-energy-food nexus in a context of the sustainable energy for all initiative. Report.
FAO. The state of food security and nutrition in Europe and Central Asia. Report, 2017.
FAO. Africa regional overview of food security and nutrition. Report, 2018.
FAO. The state of food security and nutrition in the world. Safeguarding against economic slowdowns and downturns. Report, 2019.
FAO. 2021a. Water use. Available online: http://www.fao.org/aquastat/en/overview/methodology/water-use (Accessed on 18 March 2021).
FAO. 2021b. Food and nutrition security in Latin America and the Caribbean. Available on: http://www.fao.org/americas/priorities/seguridad-alimentaria/en/ (Accessed on 26 March 2021).
Fardet, A., Lakhssassi, S., Briffaz, A., 2018. Beyond nutrient-based food indices: a data mining approach to search for a quantitative holistic index reflecting the degree of food processing and including physicochemical properties. Food Funct. 9 (1), 561–572.
Fern, E.B., Watzke, H., Barclay, D.V., Roulin, A., Drewnowski, A., 2015. The nutrient balance concept: a new quality metric for composite meals and diets. PLoS One 10 (7).
FINUT, 2017. Nutrient profiling: scientific aims versus actual impact on public health. Technical Report.
Food and Drug Administration (FDA), 2021. Food labelling- food for human consumption. Food and drug administration department of health and human services. Food and Drugs. Code of Federal Regulations-Title 21. Available online: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm (Accessed on 09 March 2021)
Franco-Arellano, B., Kim, M.A., Vandevijvere, S., Bernstein, J.T., Labonté, M., Mulligan, C., L'Abbé, M.R., 2019. Assessment of packaged foods and beverages carrying nutrition marketing against Canada's food guide recommendations. Nutrients 11, 411.
Francou, A., Hebel, P., Braesco, V., Drewnowski, A., 2015. Consumption patterns of fruit and vegetable juices and dietary nutrient density among French children and adults. Nutrients 7, 6073–6087.
FSANZ, 2016. Short guide for industry to the nutrient profiling scoring criterion in standard 1.2.7 – nutrition, health and related claims. Report.
Fulgoni, V.L., Bailey, R., 2017. Association of pasta consumption with diet quality and nutrients of public health concern in adults: national health and nutrition examination survey 2009-2012. Curr. Dev. Nutr. 1, e001271.
Fulgoni, V.L., Keast, D.R., Drewnowski, A., 2009. Development and validation of the nutrien-rich foods index: a tool to measure nutritional quality of foods. J. Nutr. 139, 1549–1554.
Fulgoni, V.L., Painter, J., Carughi, A., 2017. Association of raisin consumption with nutrient intake, diet, quality, and health risk factors in US adults: National Health and nutrition examination survey 2001–2012. Food Nutr. Res. 61, 1378567.
García, A.L., Ronquillo, J.D., Morillo-Santander, G., Mazariegos, C.V., López-Donado, L., Vargas-García, E.J., Curtin, L., Parrett, A., Mutoro, A.N., 2020. Sugar content and nutritional quality of child orientated ready to eat cereals and yoghurts in the UK and Latin America; does food policy matter? Nutrients 12, 856.
García-Herrero, I., Margallo, M., Laso, J., Battle-Bayer, L., Bala, A., Fullana-i-Palmer, P., Vázquez-Rowe, I., González, M.J., Amo-Setién, F., Durá, M.J., Sarabia, C., Abajas, R., Quiñones, A., Irabien, A., Aldaco, R., 2019. Nutritional data management of food losses and waste under a life cycle approach: case study of the Spanish agri-food system. J. Food Compos. Anal. 82, 103223.
Gibney, M.L., Barr, S.I., Bellisle, F., Drewnowski, A., Fagt, S., Hopkins, S., Livingstone, B., Varela-Moreiras, G., Moreno, L., Smith, J., Vieux, F., Thielecke, F., Masset, G., 2018. Towards an evidence-based recommendation for a balanced breakfast - a proposal from the international breakfast research initiative. Nutrients 10, 1540.
Government of Canada, 2021. Canada's Food Guide Available online: https://food-guide.canada.ca/en/ (Accessed on 26 March 2021).
Guenther, P.M., Reedy, J., Krebs-Smith, S.M., 2008. Development of the healthy eating index- 2005. J. Am. Diet. Assoc. 108, 1896–1901.
Guenther, P.M., Casavale, K.O., Kirkpatrick, S.I., Reedy, J., Hiza, H.A.B., Kuczynski, K.J., Kalhe, L.L., Krebs-Smith, S.M., 2013. Update of the healthy eating index: HEI-2010. J. Acad. Nutr. Diet. 113 (4).
Gupta, S., Hawk, T., Aggarwal, A., Drewnowski, A., 2019. Characterizing ultra-processed foods by energy density, nutrient density, and cost. Front. Nutr. 6, 70.
Gupta, S., Rose, C.M., Buszkiewics, J., Ko, L.K., Mou, J., Cook, A., Aggarwal, A., Drewnowski, A., 2020. Characterising percentage energy from ultra-processed foods by participant demographics, diet quality, and diet cost: findings from the Seattle obesity study (SOS) III. Brit. J. Nutr. 23, 1–9.
Hagmann, D., Siegrist, M., 2020. Nutri-score, multiple traffic light and incomplete nutrition labelling of food packages: effects on consumers' accuracy in identifying healthier snack options. Food Qual. Prefer. 83, 103894.
Hassan, F., Sali, S., Humayun, A., 2017. Assessment of dietary intake of adolescent girls belonging to low socio economic status: a community based study from Lahore. Prog. Nutr. 20 (1), 318–324.
Health Canada, 2014. The development and use of a surveillance tool: the classification of foods in the Canadian nutrient file according to eating well with Canada's food guide. Report.
Hess, J.M., Slavin, J.L., 2017. Healthy snacks: using nutrient profiling to evaluate the nutrient-density of common snacks in the United States. Glob. Food Sci. 00.
Hess, J., Rao, G., Slavin, J., 2017. The nutrient density of snacks: a comparison of nutrient profiles of popular snack foods using nutrient-rich foods index. Glob. Pediatr. Health 4, 1–6.
Huth, P.J., Fulgoni, V.L., Keast, D.R., Park, K., Auestad, N., 2013. Major food sources of calories, added sugars and saturated fat and their contribution to essential nutrient intakes in the U.S. diet: data from the national health and nutrition examination survey (2003–2006). Nutr. J. 12, 116.

Issa, C., Salameh, P., Batal, M., Vieux, F., Lairon, D., Darmon, N., 2009. The nutrient profile of traditional Lebanese composite dishes: comparison with composite dishes consumed in France. Int. J. Food Sci. Nutr. 60 (4).
Jessri, M., Praneet, A., L'Abbé, M.R.L., 2017. Adapting the healthy eating index 2010 for the Canadian population: evidence from the Canadian community health survey. Nutrients 9, 910.
Jomaa, L.H., Hwalla, N.C., Zidek, J.M., 2016. Development of a standardized measure to assess food quality: a proof of concept. Nutr. J. 15, 96.
Kalbar, P.P., Birkved, M., Nygaard, S.E., Hauschild, M., 2016. Weighting and aggregation in life cycle assessment. Do present aggregated single scores provided correct decision support? J. Ind. Ecol. 21 (6), 1591–1600.
Karlsen, M.C., Rogers, G., Miki, A., Lichtenstein, A.H., Folta, S.C., Economos, C.D., Jacques, P.F., Livingstone, K.A., McKeown, N.M., 2019. Theorical food and nutrient composition of whole-food plant-based and vegan diets compared to current dietary recommendations. Nutrients 11, 625.
Katz, D.L., Njike, V.Y., Faridi, Z., Rhee, L.Q., Reeves, R.S., Jenkins, D.J.A., Ayoob, K.T., 2009. The stratification of foods on the basis of overall nutritional quality: the overall nutritional quality index. Am. J. Health Promot. 24 (2), 133–143.
Kaur, A., Scarborough, P., Hieke, S., Kusar, A., Pravst, I., Raats, M., Rayner, M., 2016. The nutritional quality of foods carrying health-related claims in Germany, the Netherlands, Spain, Slovenia, and the United Kingdom. Eur. J. Clin. Nutr. 70, 1388–1395.
Kennedy, E.T., Ohls, J., Carlson, S., Fleming, K., 1995. The healthy eating index: design and applications. J. Am. Diet. Assoc. 95, 1103–1108.
Kirkpatrick, S.I., Reedy, J., Kahle, L.L., Harris, J.L., Ohri-Vachaspati, P., Krebs-Smith, S.M., 2013. Fast-food menu offering vary in dietary quality, but are consistently poor. Public Health Nutr. 17 (4), 924–931.
Krebs-Smith, S.M., Pannucci, T.E., Subar, A.F., Kirkpatrick, S.I., Lerman, J.L., Tooze, J.A., Wilson, M.M., Reedy, J., 2018. Update of the healthy eating index: HEI-2015. J. Acad. Nutr. Diet. 118 (9), 1591–1602.
Kumar, A., Sah, B., Singh, A.R., Deng, Y., He, X., Kumar, P., Bansal, R.C., 2017. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renew. Sust. Energ. Rev. 69, 596–609.
Kupirovic, U.P., Miklavec, K., Hribar, M., Kusar, A., Zmitek, K., Pravst, I., 2019. Nutrient profiling is needed to improve the nutritional quality of the foods labelled with health-related claims. Nutrients 11, 287.
Labonté, M., Poon, T., Mulligan, C., Bernstein, J.T., Franco-Arellano, B., L'Abbé, M.R., 2017. Comparison of global nutrient profiling systems for restricting the commercial marketing of foods and beverages of lo nutritional quality to children in Canada. Am. J. Clin. Nutr. 106, 1471–1481.
Labouze, E., Goffi, C., Moulay, L., Azaïs-Braesco, V., 2007. A multipurpose tool to evaluate the nutritional quality of individual foods: Nutrimap. J. Public Health Nutr. 10 (7), 690–700.
Laso, J., Margallo, M., Serrano, M., Vázquez-Rowe, I., Avadí, A., Fullana, P., Bala, A., Gazulla, C., Irabien, A., Aldaco, R., 2018a. Introducing the green protein footprint method as an understandable measure of the environmental cost of anchovy consumption. Sci. Total Environ. 621, 40–53.
Laso, J., Margallo, M., García-Herrero, I., Bala, A., Gazulla, C., Polettini, A., Kahhat, R., Vázquez-Rowe, I., Irabien, A., Aldaco, R., 2018b. Combined application of life cycle assessment and lineal programming to evaluate food waste-to-food strategies: seeking for answers in the nexus approach. J. Waste Manag. 80, 186–197.
Leivas, R., Laso, J., Abejón, R., Margallo, M., Aldaco, R., 2020. Environmental assessment of food and beverage under a Nexus water-energy-climate approach: application to the spirit drinks. Sci. Total Environ. 720, 137576.
Lobstein, T., Davies, S., 2008. Defining and labelling 'healthy' and 'unhealthy' food. Public Health Nutr. 12 (3), 331–340.
Mahlknecht, J., González-Bravo, R., Loge, F.J., 2020. Water-energy-food security: a nexus perspective of the current situation in Latin America and the Caribbean. Energy 194, 116824.
Maillot, M., Darmon, N., Darmon, M., Lafay, L., Drewnowski, A., 2007. Nutrient-dense food groups have high energy costs: an econometric approach to nutrient profiling. J. Nutr. 137, 1815–1820.
Mainardi, F., Drewnowski, A., Green, H., 2019. Personalized nutrient profiling of food patterns: Nestlé's nutrition algorithm applied to dietary intakes from NHANES. Nutrients 11, 379.
Mohtar, R.H., Daher, B., 2012. Water, Energy, and food: the ultimate nexus. Encyclopaedia of Agricultural, Food, and Biological Engineering, second ed.
Murakami, K., Livingstone, M.B.E., Fujiwara, A., Sasaki, S., 2020a. Application of the healthy eating index-2015 and the nutrient-rich food index 9.3. For assessing overall diet quality in the Japanese context: different nutritional concerns from the US. PLoS One 15 (1), e0228318.
Murphy, M.M., Barraj, L.M., Rampersaud, G.C., 2014. Consumption of grapefruit is associated with higher nutrient intakes and diet quality among adults, and more favorable anthropometric in women, NHANES 2003–2008. Food Nutr. Res. 58, 22179.
Mustafa, M.A., Mabhaudhi, T., Massawe, F., 2021. Building a resilient and sustainable food system in a changing world - a case for climate-smart and nutrient dense crops. Global Food Secur. 28, 100477.
Nhamo, L., Mabhaudhi, T., Mpandeli, S., Nhemachena, C., Senzanje, A., Naidoo, D., Liphadzi, S., Modi, A.T., 2020. Sustainability indicators and indices for the water-energy-food nexus for performance assessment: WEF nexus in practice – South Africa case study. Environ. Sci. Pol. 109, 15–24.
PAHO; WHO. Pan American health organization nutrient profile model. Report, 2016.
Peltner, J., Thiele, S., 2017. Association between the healthy eating index-2010 and nutrient and energy densities of German households' food purchases. Eur. J. Pub. Health 27 (3), 547–552.
Proctor, K., Tabatabaie, S.M.H., Murthy, G.S, 2021. Gateway to the perspectives of the food-energy-water nexus. Sci. Total Environ 764, 142852.
Purwanto, A., Susnik, J., Suryadi, F.X., de Fraiture, C., 1919. Water-energy-food nexus: critical review, practical applications, and prospects for future research. Sustainability 2021, 13.
Rauber, F., Louzada, M.L.C., Vitolo, M.R., 2014. Healthy eating index measures diet quality of Brazilian children of low socioeconomic status. J. Am. Coll. Nutr. 33 (1), 26–31.
Rayner, M., Scarborough, P., Stockley, L., 2004. Nutrient profiles: options for definitions for use in relation to food promotion and children's diets. Report.
Rehm, C.D.; Drewnowski, A. Replacing American breakfast foods with ready-to-eat (RTE) cereals increases consumption of key food groups and nutrients among US children and adults: results of an NHANES modeling study. Nutrients 2017, 9, 1010.
Rosentreter, S.C., Eyles, H., Mhurchi, C.N., 2013. Traffic lights and health claims: a comparative analysis of the nutrient profile of packaged foods available for sale in New Zealand supermarkets. Aust. N. Z. J. Public Health 37 (3), 278–283.
Rozman, U., Pravst, I., Kupirovic, E.P., Blaznik, U., Kokbek, P., Turk, S.S., 2020. Sweet, fat and salty: snacks in vending machines in health and social care institutions in Slovenia. Int. J. Environ. Res. Public Health 17, 7059.
Sacks, G., Stockley, L., Scarborough, P., Snowdon, W., Swinburn, B., 2011. Applications of nutrient profiling: potential role diet-related chronic disease prevention and the feasibility of a core nutrient-profiling system. Eur. J. Clin. Nutr. 65, 298–306.
Santos, M., Rito, A.I., Matias, F.N., Assunçai, R., Castanheira, I., Loureiro, I., 2021. Nutrient profile models a useful tool to facilitate healthier food choices: a comprehensive review. Trends Food Sci. Technol. 110, 120–131.
Scarborough, P., Rayner, M., Stockley, L., 2006. Developing nutrient profile models: a systematic approach. Public Health Nutr. 10 (4), 330–336.
Scheidt, D.M., Daniel, E., 2004. Composite index for aggregating nutrient density using food labels: ratio of recommended to restricted food components. J. Nutr. Educ. Behav. 36, 35–39.
Simpson, G.B., Jewitt, G.P.W., 2019. The development of the water-energy-food nexus as a framework for achieving resource security: a review. Front. Environ. Sci. 7, 8.
Simpson, G., Jewitt, G., Becker, W., Jessica, B., Neves, A., Rovira, P., Pascual, V., 2021. The water-energy-food Nexus index. Available online: https://www.wefnexusindex.org.
Stockholm Environment Institute (SEI). Understanding the Nexus. Background paper for the Bonn 2011 Nexus Conference. Report, 2011.
Susnik, J., Masia, S., Indriksone, D., Bremere, I., Vamvakeridou-Lydroudia, L., 2021. System dynamics modelling to explore the impacts of policies on the water-energy-food-land-climate nexus in Latvia. Sci. Total Environ. 775, 145827.
Sustainable Development Solutions Network; Bertelsmann Stiftung. SDG index and dashboards report 2017. Global possibilities. International spillovers in achieving the goals. Report, 2017.
Thompson, T.L., Singleton, C.R., Springfield, S.E., Thorpe, R.L., Odoms-Young, A., 2020. Differences in nutrient intake and diet quality between non-hispanic black and non-hispanic white men in the United States. Public Health Rep. 135 (3), 334–342.
Tomata, Y., Zhang, S., Kaiho, Y., Tanji, F., Sugawara, Y., Tsuji, I., 2019. Nutritional characteristics of the Japanese diet: a cross-sectional study of the correlation between Japanese diet index and nutrient intake among community-based elderly Japanese. Nutrition 57, 115–121.
U.S. Department of Agriculture; U.S. Department of Health and Human Services. Dietary Guidelines for Americans 2010. Report, 2010.
United Nations Statistics Division. SDG indicators. 2021. Available online: https://unstats.un.org/sdgs/indicators/database/. (Accessed on: 24 March 2021).
Van Dooren, C., Douma, A., Aiking, H., Vellinga, P., 2017. Proposing a novel index reflecting both climate impact and nutritional impact of food products. Ecol. Econ. 131, 389–398.
Van Kernebeek, H.R.J., Oosting, S.J., Feskens, E.J.M., Gerber, P.J., De Boer, I.J.M., 2014. The effect of nutritional quality on comparing environmental impacts of human diets. J. Clean. Prod. 73, 88–99.
Vázquez-Rowe, I., Laso, J., Margallo, M., García-Herrero, I., Hoehn, D., Amo-Setién, F., Bala, A., Abajas, R., Sarabia, C., Durá, M.J., Fullana-i-Palmer, P., Aldaco, R., 2020. Food loss and waste metrics: a proposed nutritional cost footprint linking lineal programming and life cycle assessment. Int. J. LCA 25, 1197–1209.
Vieux, F., Privet, L., Masset, G., 2018. Food and diet-based validations of a Nestlé nutrient profiling system for reformulation in two nationally representative surveys. Brit. J. Nutr. 120, 1056–1064.
Voinea, L., Popescu, D.V., Negrea, M.T., 2015. Good practices in educating and informing the new generation of consumers on organic foodstuffs. Amfit. Econ. 17 (38), 488–506.
Walker, C., Gibney, E.R., Hellweg, S., 2018. Comparison of environmental impact and nutritional quality among a European sample population – findings from the Food4me study. Sci. Rep. 8, 2330.
WHO, 2010. Nutrient profiling. Report.
WHO. Who regional office for Europe nutrient profile model. Report, 2015.
WHO, 2016. WHO nutrient profile model for the Western Pacific region. A tool to project children from food marketing. Report.
WHO. Nutrient profile model for the marketing of food and non-alcoholic beverages to children in the WHO Eastern Mediterranean region. Report, 2017a.
WHO, 2017b. WHO nutrient profile model for south-East Asia region. To implement the set of recommendations on the marketing of foods and non-alcoholic beverages to children. Report.
WHO. Nutrient profile model for the WHO African region. A tool for implementing WHO recommendations on the marketing of foods and non-alcoholic beverages to children. Report, 2019.
Wu, Y., Hu, H., Dai, X., Zhang, H., Xu, F., Hu, H., Guo, Z., 2020. Comparative study of the nutritional properties of 67 potato cultivars (solanum tuberosum L.) grown in China using the nutrient-rich foods (NRF11.3.) index. Plant Foods Hum. Nutr. 75, 169–176.
Zhang, C., Chen, X., Li, Y., Ding, W., Fu, G., 2018. Water-energy-food nexus: concepts, questions and methodologies. J. Clean. Prod. 195, 625–639.