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A method to rapidly match environmental impact data to > 60 dietary datasets

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ABSTRACT

There is growing interest in assessing the environmental impacts of diets due to the awareness of the link with human and planetary health. Until now, a limiting factor in this field has been linking information on the environmental impacts of foods to detailed individual-level dietary data that reflects the food consumption habits of people. Here we present i) a method to link environmental impact data to a food description and classification system (FoodEx2); ii) a resulting dataset of environmental impact values matched to 4089 food descriptors; and iii) an example of applying this data to assess the environmental footprints of diets from Brazil and the USA. Our methodology and dataset enhance the interoperability between environmental and nutrition data, facilitate the assessment of environmental impact of dietary intakes from different countries, and can be used by researchers, policy makers, practitioners and consumers to reduce the environmental impact of diets.

Keywords: environmental impact; dietary assessment; greenhouse gas emissions; food description system; food systems; sustainability; sustainable food consumption; sustainable diets

INTRODUCTION

Food is essential for human survival and well-being, but it also significantly impacts the planet and its climate (1). Food systems, which include all the activities and processes involved in producing, processing, distributing, consuming, and disposing of food, are affected by and contribute to climate change. Currently, global food systems account for about a third of all greenhouse gas emissions (2), 70% of freshwater withdraws (3) and 37% of land area (4). Reducing the environmental footprint of food systems is among the major actions for mitigating climate change and environmental degradation as well as ensuring food security for current and future generations (5).

One of the key challenges in transforming food systems is to understand and measure the environmental impacts of different dietary patterns. This requires linking environmental impact information to dietary data at different levels of aggregation. The environmental dimension of food systems is often explored by estimating the impacts of agricultural production and food processing (2,6–8), or using indirect dietary assessment methods such as Food Balance Sheets, or Household Consumption Surveys (9,10). Because food system transformation encompasses changes in consumer behaviour, there is a growing interest in capturing the environmental impacts of individual dietary choices as this would allow for the identification of groups of individuals with specific dietary patterns and the design of targeted interventions. This can be achieved by estimating the pressures of diets on the environment using direct dietary assessment methods. These methods use individual-based surveys, such as 24-hour dietary recalls or food records (also called food diary). Recently, more studies have explored the environmental impacts of individual food consumption using direct dietary assessment methods (11–16).

Combining environmental data with individual-level quantitative dietary data involves integrating knowledge from multiple disciplines including nutrition, agriculture, ecology, data science. Coordinating across these disciplines requires a shared understanding of concepts, methodologies, and goals. While individual dietary data can be highly detailed, culturally nuanced, and personal, environmental data are often aggregated and generalised. Dietary and environmental data are typically expressed in different units that need to be converted into compatible units for analysis, requiring careful methodological considerations. Both environmental and dietary datasets often have gaps, whether due to incomplete reporting, seasonal variations, or technical limitations in data collection. Filling these gaps requires careful data handling. These peculiarities make the task of linking environmental and dietary data a demanding but crucial step in understanding the interplay between food systems, human health, and environmental sustainability (17–19).

In addition, the lack of harmonisation and standardisation on how foods are described among different disciplines hinders the integration of data and approaches for nutritional and environmental analysis (19). This highlights a need for implementing data harmonisation options that can facilitate the estimation of the environmental impacts of individual food consumption using direct dietary assessment methods. Some initiatives exist to standardise food description, allowing for a better integration across disciplines that span the entire food journey from farm-to-fork. Examples include Langual (20), FoodOn (21), and FoodEx2 (22), which are controlled vocabularies used to name all parts of animals, plants and fungi used as foods and their derived products. Because these vocabularies standardise food description across different stages of food systems, as well as across disciplines, they could allow for a better and faster integration between environmental and nutritional assessments. FoodEx2, in particular, has been used to integrate dietary and environmental assessment in European countries (11,23) and is incorporated into Langual and FoodOn. Over 60 individual dietary surveys from many countries, including low- and middle-income countries, have been harmonised with FoodEx2 (24). Linking globally representative environmental impact data to FoodEx2 would facilitate the assessment of the environmental footprints of diets in different parts of the world.

In this article, we describe a methodology to link environmental impact data to FoodEx2 base terms. This linkage facilitates the estimation of the environmental impacts of diets, using information from dietary surveys that have been harmonised with FoodEx2. We also present the resulting resource with environmental impact values linked to 4089 FoodEx2 base terms, and describe its application to estimate the environmental impacts of the diets in Brazil and the United States of America (USA).

METHODS

Interoperable Dietary and Environmental Assessment dataset (IDEA)

The Interoperable Dietary and Environmental Assessment dataset (IDEA) was developed in 2019 (25,26) and updated in 2021-2023. It aims to facilitate the assignment of environmental impact metrics to individual-level food consumption data, such as those available in the FAO/WHO Global Individual Food Consumption Data Tool (FAO/WHO GIFT) (27,28) and elsewhere.

IDEA uses environmental impact values from a meta-analysis (8) that compiled data from around 38,000 farms across 119 countries, including low- and middle-income countries. The meta-analysis used attributional Life Cycle Assessment (LCA) to estimate the greenhouse gas emissions, freshwater withdrawals, stress-weighted water use, land use, acidifying emissions, eutrophying emissions of 43 food products. The environmental impact values of these 43 products were manually matched to 4089 FoodEx2 base terms (Figure 1), using the closest food match. We used FoodEx2 Exposure hierarchy catalogue, version MTX 14.2, released in March 2023 (29). When no environmental values existed for a food, proxy values from a similar food were used. For example, beans and lentils were assigned values from “other pulses”. If the item was a complex product (i.e., mixed/composite dishes), the matching was made considering the ingredient with the highest raw weight by consulting common recipes. These matches were then reviewed by a second researcher.

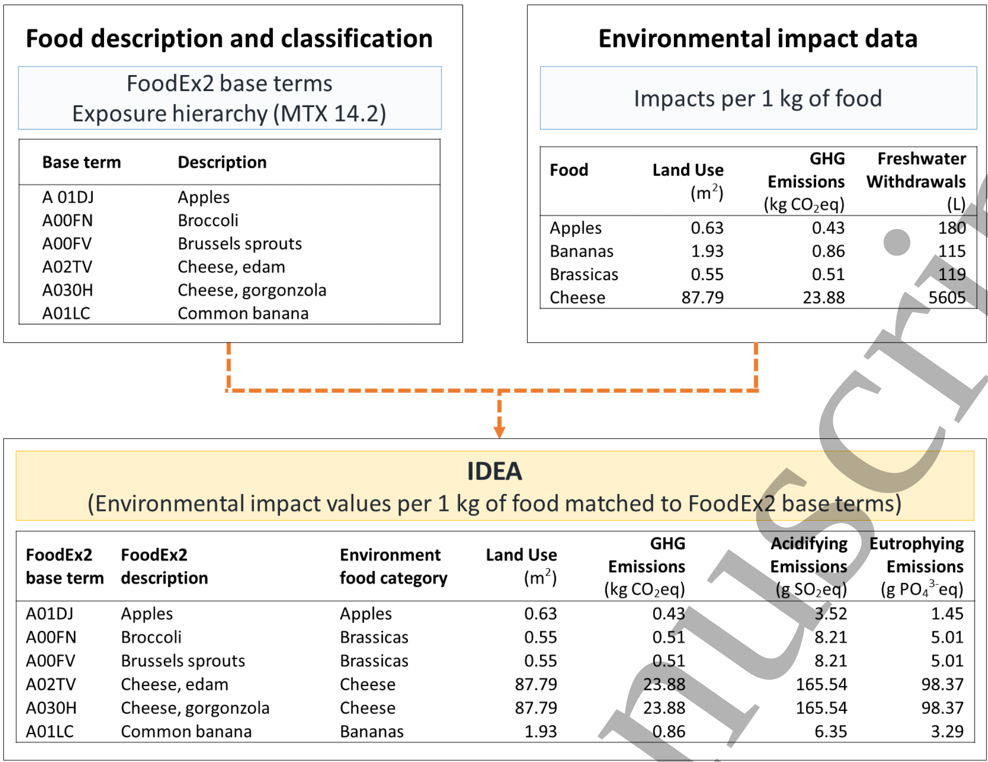

Figure 1. Overview of the methodology: matching 4089 FoodEx2 base terms to 43 environmental impact values from a meta-analysis (8). This illustration summarises how IDEA (Interoperable Dietary and Environmental Assessment dataset) was built. Food description and classification from the FoodEx2 exposure hierarchy catalogue is matched with environmental impact data to enable a quick assessment of diets.

IDEA presents environmental impact values for 1 kg of food as purchased at retail point. A correction in the weight of some foods was necessary when the functional unit for the environmental impacts was 1 Litre or when the mass was significantly different than the amount usually consumed due to the inflated effect of water (Figure 1). To minimize the risk of overestimating the results, environmental impact values were corrected following the same approach adopted by a previous study (14). We highlight that IDEA does not include food composition (nutrient) information – it is a mapping between FoodEx2 codes and environmental impact values only.

Since IDEA was developed through a manual match between FoodEx2 base terms and environmental impact data, a careful review of the matching process was performed to minimise the impact of possible human error. The review started with an initial screening of the dataset by two nutrition data experts. The screening raised 919 queries that were examined by one nutrition expert who solved minor queries (kept or changed the values) or marked for discussion. These queries included cases in which the environmental impact was incorrect; no environmental impact data was assigned to FoodEx2 base terms; or the environmental food commodity did not seem appropriate for the FoodEx2 base term. Some queries could not be solved between these two experts and were discussed with a wider multidisciplinary team, including economists, data scientists, chemical engineers, biologists. These complex queries were related to three food groups: (i) terrestrial invertebrates; (ii) food supplements, additives and similar; and (iii) composite dishes. To inform decisions on the best approach in relation to these food groups, we identified how often they were reported in the FAO/WHO GIFT dietary datasets available online as of November 2022 (35 datasets from 25 countries), their contribution to energy intake, and how changes on the environmental impact values affected estimations. Details of the complex queries, and solutions applied to them, are available in Supplementary Appendix 2. Subsequent revision rounds detected 168 queries related to inconsistencies between values used in IDEA and other environmental impact datasets (15,16,23,30,31). After completion of the revision, 978 changes were applied to the initial version of IDEA, detailed in Supplementary Appendix 2.

The initial version of IDEA was based on the Exposure hierarchy catalogue from June 2020 (version MTX 11.2). To reflect regular updates in FoodEx2 catalogue, two nutrition experts assigned environmental impact values to 11 FoodEx2 base terms added to the Exposure hierarchy catalogue between June 2020 to June 2023 (version MTX 14.2), following the same methodology used in the initial development (25,26,32). All decisions made during the revision process and the rationale behind them, along with new FoodEx2 base terms added are available in Supplementary Appendix 2.

A subsequent technical validation of the matching was performed in three steps: i) food-level assessment of the correlation and agreement between environmental data used in IDEA and other environmental impact data mapped to individual-level dietary information found in the literature; ii) diet-level assessment of the matching reliability in estimating the environmental impact of diets; and iii) case studies using IDEA to estimate the environmental impact of diets from two different countries.

Food-level assessment

A common approach to validate data is to consult other data sources in which all or part of the same information is available, aiming to compare the data case by case and to calculate the degree of agreement between them (33). This allows to check the relative validity, since a golden standard is not available. We identified three environmental impact datasets that could be used to assess the relative validity of our matching. One of them is directly but partially matched to FoodEx2 base terms. SHARP linked greenhouse gas emissions and land use to FoodEx1, an initial version of FoodEx (23). The other two datasets matched environmental impact values to a dietary survey that have been harmonised with FoodEx2. Rose et al (2019) matched greenhouse gas emissions to the United States National Health and Nutrition Examination Survey (NHANES) (15). Garzillo et al (2019) matched greenhouse gas emission, water use and land use to the Brazilian Food Consumption Survey (16).

The relative validity was assessed on a food-by-food basis, before and after technical validation. Similarities and differences between values used in IDEA and the three alternative datasets were assessed in two ways. First, we calculated Spearman correlation coefficients between greenhouse gas emissions from IDEA and three comparison datasets (15,16,23). Second, we performed agreement tests between SHARP and IDEA. SHARP was selected for these tests because it has a higher number of directly comparable foods with IDEA than Garzillo and Rose (Table 2). Greenhouse gas emissions of foods available in both IDEA and SHARP were ranked and split into quintiles. Quintile rankings of agreement were checked by calculating weighted kappa statistics. For food items not ranked in the same quintile, we assessed whether values from SHARP were within the 5th and 95th percentiles available in IDEA. If they were not, a thorough investigation of the values was performed by consulting other environmental datasets (15,16,30,31). When values from IDEA were similar to other sources, they were kept the same. Otherwise, further changes were applied to the IDEA. Details of these changes are described in the Supplementary Appendix 2, under revision round 2.

Diet-level assessment

Similarities and differences between IDEA and alternative datasets were also assessed at the diet-level. The Brazilian Food Consumption Survey (POF 2008-2009) (34) was used to evaluate the reliability of IDEA to estimate the environmental impacts of individual food consumption. This survey was selected because it has been harmonised with FoodEx2, and there are environmental data matched to all foods reported in the diet. For this analysis, greenhouse gas emissions for the overall diet and by food groups were estimated using IDEA and Garzillo datasets, considering the food groups defined by the Food and Agriculture Organization (35). Garzillo (16) data was considered as a reference since it was developed specifically to estimate environmental impacts of the Brazilian diet. Pearson's correlations were calculated to assess the correlation between estimations made from the two environmental datasets. Following this assessment, additional changes were applied to IDEA to minimise overestimation related to meat products. Details of these changes are described in Supplementary Appendix 2, under revision round 3.

Case studies

For validation purposes, we present two case studies of one middle- and one high-income country (Brazil 2008-2009 and USA 2015-2019). These examples demonstrate how IDEA can rapidly link environmental impact values to different dietary datasets through the FoodEx2 classification system.

Dietary data previously harmonised with FoodEx2 were sourced from the FAO/WHO GIFT (28) and Global Dietary Database (36) for Brazil and the USA, respectively. The environmental impacts of the average diet consumed by men and women, individuals from different age groups and dietary patterns (low and high meat) are presented. In the two case studies, low and high meat diets were defined by quintiles of meat consumption. Individuals considered as having a low meat diet are those in the lowest quintile of meat consumption (grams/person/day). These individuals might consume no meat or consume a small amount of meat compared to others. Similarly, individuals considered as having a high meat diet are those in the highest quintile of meat consumption, meaning they consume more meat comparatively to others. We summarised the environmental impacts of individuals in low and high meat diets, as well as the impacts of the average diet considering all individuals in each case study.

For illustration purposes, the environmental impacts of diets in Brazil and the USA are reported by 1000 kcal because: (i) this is a customarily acknowledged functional unit; (ii) it is simple and easy to understand; (iii) it is a way of normalizing/adjusting the results for energy intake, considering that a higher energy intake is likely to generate higher environmental impacts (10,37). However, once environmental data has been linked to dietary data, it is also possible to present results using different functional units that consider protein and micronutrient intakes as well as dietary quality and diversity (37). How results are displayed will vary according to the purposes of the user.

RESULTS

Food-level assessment

Greenhouse gas emissions in the initial version of IDEA were strongly correlated to values in all comparison datasets, and the correlation increased following the technical validation (Table 1). These correlations range from 0.616 to 0.725. However, the number of directly comparable food items between datasets was low. SHARP had the highest number of common food items with our resource (n=936, 20%), which is explained by the similar nature of both SHARP and IDEA.

Table 1. Spearman correlation coefficients between greenhouse gas emissions from IDEA and other datasets, before and after technical validation.

Environment data source	Technical validation			
	Before		After	
	N	rho	N	Rho
SHARP (23)	945	0.699	936	0.725
Rose (15)	680	0.572	675	0.616
Garzillo (16)	520	0.625	518	0.635

All p-values are lower than 0.001; n: number of food items; rho: Spearman correlation coefficients.
IDEA: Interoperable Dietary and Environmental Assessment dataset

Before technical validation, of the 945 food items comparable with SHARP, 47% (n = 445) were ranked in the same greenhouse gas emission quintile and the kappa statistic was 0.536 with p-value < 0.001 (Table 2). Of the food items ranked in different quintiles (n=500), 90% had environmental values similar to other datasets (15,16,30,31) and were therefore unchanged. Values from the remaining food items were changed, as described in Supplementary Appendix 2 under revision round 2. After adjustments from the technical validation, the proportion of items ranked in the same quintile slightly increased to 49% and kappa statistics increased to 0.560 ($p < 0.001$).

Table 2. Quintile rankings of agreement for greenhouse gas emissions between IDEA and SHARP, before and after technical validation.

	Technical validation									
SHARP (23)	**Before**					**After**				
	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**
Q1	85	57	46	1	0	79	57	32	12	0
Q2	46	76	53	13	1	49	88	49	3	0
Q3	34	52	48	31	24	35	41	69	37	7
Q4	23	1	17	110	38	24	1	11	97	56
Q5	1	3	25	34	126	1	0	26	38	124

Q1-Q5 corresponds to quintiles 1-5. IDEA: Interoperable Dietary and Environmental Assessment dataset

Diet-level assessment

The average daily greenhouse gas emission per person and per food group estimated using Garzillo and IDEA are described in Table 3. Daily results from the two environmental datasets were highly correlated ($r = 0.90$). However, results from IDEA are 30% higher than those from Garzillo. This difference is mainly explained by the food groups “beverages”, “fish”, and “milk and milk products” for which emission intensities are higher in IDEA than in the Garzillo. For the food groups “sweets and sugars”, and “vegetables”, the correlation between the two environmental datasets was weak ($r < 0.40$). For vegetables, daily emissions were very similar between the two data sources (~0.02 kg of CO_2 eq./person/day) and the weak correlation is explained by the great variability of emissions among different vegetables. For sweets and sugar, the weak correlation is explained by different emissions intensities that results in different estimates (0.11 vs 0.20 kg of CO_2 eq./person/day). However, these differences have a low influence in the final estimation of emissions from the Brazilian diet, since they represent up to 3% of the total emissions per day.

Case studies

The case studies show that by using IDEA to link environmental impact values to individual-level dietary data, it is possible to identify nuances based on individual characteristics. For instance, while environmental impacts per 1000 kcal consumed do not seem to vary according to sex, there are differences according to age group (Figures 2 and 3). Although impacts vary with age in both countries, each country shows a different pattern. Diets with the highest environmental footprints are observed among those aged 66 years or older in Brazil and those aged 50-65 years in the US.

Table 3. Greenhouse gas emissions from the Brazilian diet by food groups, according to different environmental impact datasets. Values are expressed as the average kg of CO_2 eq. per person per day (95% confidence interval).

Food groups	Garzillo (16)	IDEA	Pearson correlation
Cereals	0.273 (0.271; 0.275)	0.386 (0.383; 0.389)	0.91
Roots, tubers and plantains	0.019 (0.019; 0.020)	0.039 (0.038; 0.040)	0.80
Pulses, seeds and nuts	0.066 (0.065; 0.067)	0.109 (0.108; 0.110)	0.73
Milk and milk products	0.14 (0.137; 0.144)	0.342 (0.334; 0.349)	0.87
Eggs	0.047 (0.046; 0.048)	0.059 (0.058; 0.061)	1.00
Fish	0.221 (0.211; 0.232)	0.534 (0.513; 0.554)	0.74
Meat	3.141 (3.102; 3.18)	2.926 (2.894; 2.959)	0.95
Vegetables	0.024 (0.023; 0.025)	0.029 (0.029; 0.030)	0.34
Fruits	0.075 (0.073; 0.077)	0.065 (0.064; 0.067)	0.77
Fats and oils	0.018 (0.018; 0.019)	0.064 (0.062; 0.066)	0.99
Sweets and sugars	0.113 (0.11; 0.116)	0.204 (0.192; 0.215)	0.29
Spices and condiments	0.001 (0.001; 0.001)	0.002 (0.001; 0.002)	0.80
Beverages	0.223 (0.219; 0.227)	0.937 (0.927; 0.947)	0.61
Composite dishes	0.578 (0.562; 0.594)	0.838 (0.819; 0.857)	0.50
Snacks	0.012 (0.012; 0.013)	0.010 (0.010; 0.011)	0.78
All food groups	4.95 (4.90; 4.99)	6.54 (6.50; 6.59)	0.90

Food groups were defined by the Food and Agriculture Organization (35).

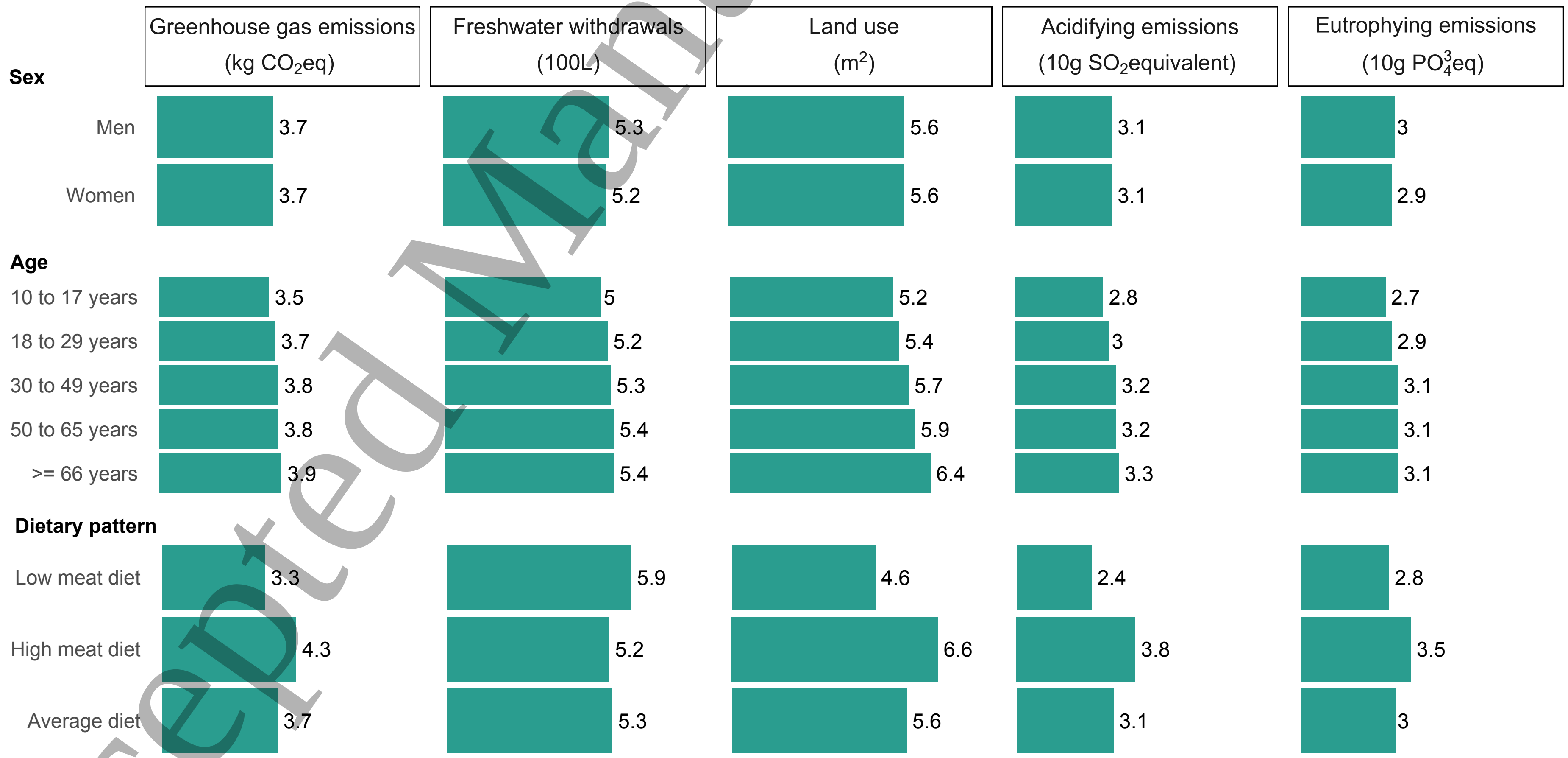

Figure 2. Environmental impacts per 1000 kcal consumed by individuals in Brazil, by sex, age group, and dietary patterns.
This figure illustrates the environmental impacts of the Brazilian diet during 2008-2009 accounting for six environmental impact categories: Greenhouse gas emissions (kg CO2 eq.), Freshwater withdrawals (1000 L), Stress-weighted water use (1000 L), Land use (m2), Acidification Potential (g SO2 eq.) and Eutrophication Potential (g PO4 eq.). Impacts are presented per 1000 kcal consumed, by sex, age group and dietary pattern. Low and high meat dietary patterns were defined by quintiles of meat consumption. Individuals

considered as having a low meat diet are those in the lowest quintile of meat consumption (grams/person/day). Similarly, individuals considered as having a high meat diet are those in the highest quintile of meat consumption. The average diet considers all individuals in the survey, including low and high meat.

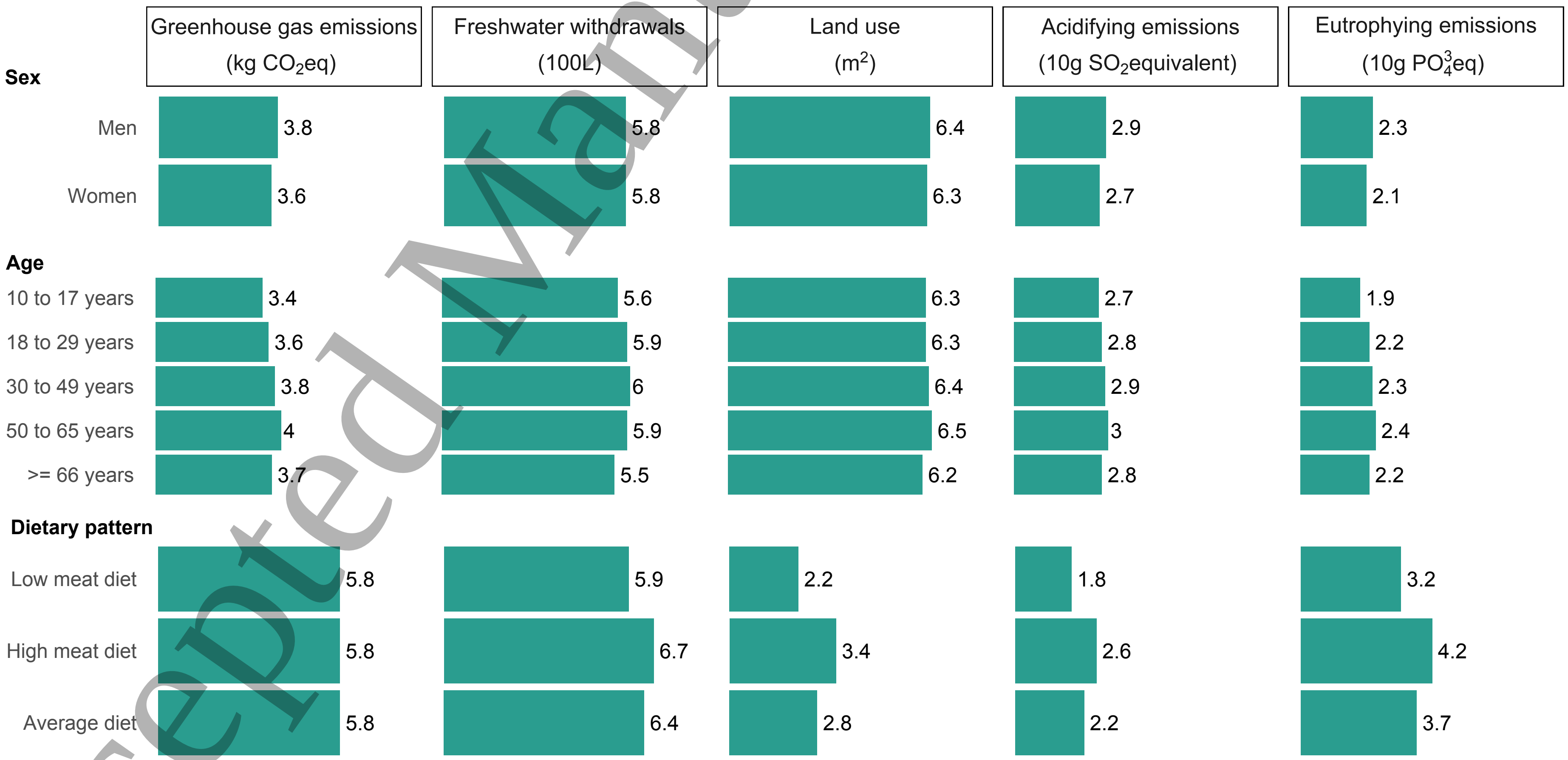

Figure 3. Environmental impacts per 1000 kcal consumed by individuals in the United States by sex, age group, and dietary patterns. This figure illustrates the environmental impacts of diet in the United States during 2015-2016 accounting for six environmental impact categories: Greenhouse gas emissions (kg CO2 eq.), Freshwater withdrawals (L), Stress-weighted water use (L), Land use (m2), Acidification Potential (g SO2 eq.) and Eutrophication Potential (g PO4 eq.). Impacts are presented per 1000 kcal consumed, by sex, age group and dietary pattern. Low and high meat dietary patterns were defined by quintiles of meat consumption. Individuals

considered as having a low meat diet are those in the lowest quintile of meat consumption (grams/person/day). Similarly, individuals considered as having a high meat diet are those in the highest quintile of meat consumption. The average diet considers all individuals in the survey, including low and high meat.

DISCUSSION

Interest in assessing the environmental impact of individual food consumption is increasing rapidly, but this assessment is limited by data availability and resources. There are several recognised datasets for the environmental impacts of foods, such as SHARP (23), AGRIBALYSE (30), and SU-EATABLE LIFE (31). However, these resources are focused on European food production and consumption. To provide a better estimation of the environmental impacts of diets in low- and middle-income countries, IDEA uses environmental impact data from a comprehensive meta-analysis summarising the impacts for 43 food commodities representing ~90% of global dietary energy and protein availability (8). Although environmental impacts are not provided on a country-by-country basis in the meta-analysis, average values and percentiles were calculated using data from 38,000 farms located in 119 countries.

IDEA, released with this paper as Supplementary Appendix 1, was developed by a multidisciplinary team linking environmental impact values to 4089 FoodEx2 base terms. The analysis of greenhouse gas emissions at the food-level showed that IDEA has a moderate to high correlation to similar environmental datasets. This is explained by the natural variation of greenhouse gas emissions from the same food, that has been described as varying by 460% between different producers and assessment methods (8).

It is worth noting that other food vocabularies, such as FoodOn, or dietary surveys can link their food descriptors to environmental impact data directly. Although many food vocabularies exist (20,38) our resource is built on the FoodEx2 system for two main reasons. First, the system was designed to have the ability to link different food databases (consumption, composition, hazards, environmental impacts, etc). Second, the system has been used at the global level to harmonise dietary surveys with the support of the Food and Agriculture Organization of the United Nations and the Global Dietary Database (39). A disadvantage of using FoodEx2 is that the process of classifying and describing foods is performed manually and relies heavily on prior knowledge and discretion of the professional describing the foods. Hence, our resource is most effectively applied after the assignment of the FoodEx2 description and classification. For dietary surveys previously harmonised with FoodEx2 or food vocabularies integrated to FoodEx2, our resource offers an opportunity to facilitate the process.

In relation to greenhouse gas emissions per person per day of the Brazilian diet, results from IDEA were highly correlated with those from Garzillo (16), though they were 30% higher. This is explained by different emission intensities for “beverages”, “fish”, and “milk and milk products” between the two environmental impact datasets. These findings are consistent with previous studies. Carvalho et al. (2023) estimated greenhouse gas emissions of the Portuguese diet using three different datasets (11). Similar to our findings, they observed moderate to high correlation between environmental datasets and a possible overestimation of dietary environmental impacts when using the meta-analysis (8). Sugimoto et al. (2020) (40) analysed the Japanese diet and found that mean daily per capita values of diet-related greenhouse gas emissions vary depending on the environmental dataset used. However, the major food contributors to diet-related emissions remain consistent across various environmental datasets, namely animal-source foods.

We stress that is not the aim of this study to generate more accurate results for Brazil and the US. We estimated environmental impacts using IDEA and other datasets (Garzillo for Brazil; Rose for US) to show how IDEA performs in estimating environmental impacts in comparison with other environmental datasets (15,16). We used these two examples to show that estimating environmental impacts using IDEA provides similar estimates as if matching to each dietary dataset individually. Although these datasets compiled data to estimate environmental impacts specifically for each country, they did not use country-specific data only but also considered data from other countries. This is a common limitation in the field at the time of writing. Not all countries have environmental data matched to dietary data. For these cases, IDEA is a good option.

IDEA's main advancement is a matching methodology and resulting resource that is built for i) interoperability between environmental and dietary data, and ii) future use. Interoperability refers to standardised mechanisms that allow data to flow between diverse systems with minimal human intervention. Previously, similar foods were described differently in environmental and dietary data sources, and this lack of harmonisation of the food description compromises a more holistic analysis of individual food consumption through a food systems lens. By using FoodEx2, IDEA allows for more harmonised and precise food description for dietary and environmental assessments. Importantly, IDEA's structure is adaptable and could be scaled to incorporate spatially-explicit, country-specific or refined food categories as they become available.

Matching food descriptions from environmental to dietary sources is a critical step to assess the environmental impacts of diets (17). Previous studies (15,16) have independently matched environmental data to specific dietary data, taking months of researcher time. Our approach aims to make the data usage more comprehensive and efficient. By taking advantage of the harmonisation of food descriptions, IDEA enables the integration of environmental impact aspects into dietary surveys and contributes to the generation of evidence to promote healthy diets from sustainable food systems. The resource is among the first to provide global environmental impact data for a large number of harmonised food descriptors, allowing for a rapid connection of environmental impact values to dietary data. The rapid connection is possible because environmental impact values are matched to a food description system that has been used by many countries and international organisations since 2011 to describe foods from individual-level food consumption surveys (24). A demonstrated use of the IDEA is the one used to calculate environmental impact results for more than 60 datasets from over 30 countries published in the FAO/WHO GIFT website (27).

Finally, considering that FoodEx2 descriptors have been used for a variety of data types (i.e., dietary data, food composition, chemical occurrence data), our matching method provides an opportunity to link environment impact considerations to other disciplines underpinning food systems, such as food composition and food safety, nutritional epidemiology, environmental sciences, agriculture economics.

Limitations

The selection of any dataset to assess the environmental impact of individual food consumption involves trade-offs. There are a few limitations to using data from a meta-analysis (8) for this purpose. The first one refers to the scope of the life cycle assessment (LCA) cradle-to-retail, which does not account for consumption and disposal stages such as storage, cooking and discarding of foods at home. Not accounting for the post-retail stage may result in an underestimation of the environmental impacts, since the impact of cooking accounts for up to 60% of the total environmental impacts of foods (41). The exclusion of these stages is due to two main reasons. First, the amount of detailed information required to assess the impact of cooking, considering food type and country. For example, information related to the cooking method, appliance used, fuel type, cooking time. This information is not captured in most dietary surveys. Second, most LCA studies focus on the impacts of food production or up to the retail point, but as more LCA studies extend their scope, it will be possible to consider impact that includes the consumption stage.

The second limitation refers to matching environmental data of 43 broad food categories to 4089 specific foods due to the lack of LCA information on specific food items. The matching approach of assigning environment values from a limited number of food categories to specific food items based on the best available data has been used by several studies (14,42–44) and could be updated as more LCA data for specific food items become available. One such study has estimated 26 crop and 19 livestock categories which focused on within-farm-gate pressures but did not follow an LCA approach (45). Due to methodological differences between Halpern and Poore and Nemecek, we preferred not to combine these two results. Nevertheless, it has been argued that as few as 30 food categories are sufficient to distinguish the impacts of different dietary patterns (46). In addition, the 43 food categories used in our study represent around 90% of global dietary energy and protein availability worldwide (8). Hence, we do not anticipate a significant change in the estimation of the environmental impact of diets using our resource.

It is worth noting that the environmental data (8) linked to FoodEx2 provides global average values for the environmental impacts of foods. Global averages are good estimates when no regional, national or subnational values are available, offering a baseline for comparative analysis and often representing the only feasible data option in many low- and middle-income settings. For example, the EAT-Lancet Commission employed global average environmental footprints to develop its planetary health diet recommendations, demonstrating how such data can provide a framework for informing policy and nutrition guidance at a global scale (47)(add citation). However, regional and national-specific data are important for better representation of the actual environmental impacts and further work is needed to fill this gap. This limitation could be addressed in the future by using Foodex2 to harmonise the Food and Agriculture Biomass Input-Output model (FABIO), which has environmental impact data (biomass, land use, water, and greenhouse gas emissions) for 191 countries and 123 agricultural and food products (48). If country specific LCA data was supplied, this could further support policy formation and information provision. Likewise, the environmental impact for 16 crop commodities from a recent study could be linked to the FoodEx2 for a very fine resolution analysis (49). As such, IDEA should be seen as a necessary starting point for more granular assessments as more granular data become available.

Another limitation is the estimation of environmental impacts for non-disaggregated mixed dishes, in particular meat-based dishes. For non-disaggregated mixed dishes, the matching was made considering the ingredient with the largest raw weight by consulting common recipes. This approach has limitations because some products may have their impacts underestimated if an animal-based ingredient was the second or third ingredient by weight, and because standardised recipes are considered, which may not reflect the recipes that were consumed. Nevertheless, we expect this limitation to have a low influence on our results, since most dietary datasets provide disaggregated recipe information. For the dietary surveys in Brazil and the US, for example, the non-disaggregated mixed dishes represent 7% and 11% of daily dietary energy intake, respectively. Future work could link environmental values of composite dishes to their specific ingredients to accurately calculate impacts, but due to the complexity and variability of composite dishes, large recipe datasets from different countries or regions are needed to reduce the error. The calculation of the environmental impacts of composite dishes has begun to be assessed (50–52) and it is hoped this will inform future work.

The final limitation refers to the focus on greenhouse gas emissions to assess the level of agreement between the resulting IDEA with other environmental impact datasets. This does not mean that other environmental impacts like water use, and land-use will behave similarly. Data on environmental impacts other than greenhouse gas emissions are scarce, and when assessed, the methodological approach varies as there are no agreed standards for their development. For example, water related indicators can be assessed using the water footprint or freshwater withdrawals methodologies (53); those methods are completely different, and their comparison is not appropriate. Therefore, to avoid unfair comparisons, we use only greenhouse emissions and acknowledge the need for further work to review the methodologies of other impacts.

To address these limitations, IDEA has been designed to be extensible, allowing for the incorporation of more detailed, spatially explicit data, finer food classifications, and methodological advances over time.

Future applications

The method and data described in this paper facilitates the connection between environmental impact values and dietary data that has been harmonised with

FoodEx2. This is a valuable feature, considering that more than 60 dietary datasets have been mapped to the FoodEx2 food classification system, such as those available in the EFSA Comprehensive European Food Consumption Database (24), FAO/WHO GIFT (27) and the Global Dietary Database (36). By using IDEA, these platforms could offer consistent estimates of the environmental impacts of individual food consumption across different countries and regions, and across time-periods. This can aid policymakers, public health professionals and researchers in further understanding and comparing the environmental impacts of diets of their own countries and against others. It also provides opportunities for more comprehensive and holistic understanding of sustainable food consumption where health, nutritional and environmental aspects could be analysed together. While IDEA could support the development of environmental indicators to complement other analysis, these indicators need to be supported by an understanding of socio-political and economic aspects to better inform decision making.

IDEA has many applications for diverse users. Researchers can use the resource to easily assess the environmental impact of food consumption, providing details on the environmental impacts of different dietary patterns consumed by a given population, and monitor changes over time. Scenarios could be tested to understand the environmental benefits of potential dietary changes and interventions under an environmental lens. This information, together with economic and health data, could then be used by policymakers to inform evidence-based policies to promote climate change mitigation, and the consumption of nutritious but less resource-intensive foods. Policymakers can use our method and dataset to generate evidence that will inform and support the development of dietary guidelines and food policies aimed at promoting environmentally sustainable diets. By understanding the environmental impacts associated with different dietary patterns of individuals, policymakers can tailor recommendations to improve food environments and encourage individuals to make healthier and more sustainable dietary decisions.

Food system researchers and practitioners can use IDEA to support the assessment of trade-offs and win-wins of sustainable diets. In particular, food manufacturers, retailers and potentially the hospitality sector could use the resource to assess the environmental impact of their products and implement eco-labelling schemes or certifications. By accessing transparent information about the environmental footprint of food products, consumers can make conscious purchasing decisions that align with their sustainability values. Additionally, companies such as catering and hospitality business and food manufacturers can use this information to identify areas for improvement in their menu creation, new product development, and similar, to understand the environmental impacts of their products.

A preliminary version of the IDEA has already been implemented by nutrition application programming interface (API) to estimate the environmental impact of recipes and generate carbon labels (54). The final dataset presented here could be implemented to provide more accurate estimations of greenhouse gas emission but also other environmental impacts. Looking ahead, IDEA also serves as a foundation for further methodological advances, including the integration of spatially explicit environmental data at national and subnational levels, as well as information on a broader range of food products, which will expand its scope and precision.

Finally, the dataset can also be used to support consumer's education. Educators and health professionals can leverage the dataset to inform consumers about the environmental implications of their diets. For example, interactive tools or apps used by individuals to explore the implications of dietary preferences on human and planetary health. The dataset can also be used in student and practitioner education as a source for data "hack" events, similar to the events in place since 2017 (55).

CONCLUSION

The matching method and resulting resource presented in this paper represent a significant advancement in the assessment of the environmental impacts of individual food consumption. It accelerates the linkage of environmental impact data to multiple dietary surveys harmonised with FoodEx2. The resource presented a moderate to high correlation and a moderate level of agreement with other environmental datasets and offers global averages and percentiles of the environmental impacts of foods, considering production methods in low- and middle-income countries. In addition, it can be considered a reliable tool to estimate the environmental impacts from individual food consumption, providing an understanding of the environmental implications of dietary choices made by individuals. This complements country-level statistics on the environmental impact of food production, such as those shared through FAOSTAT (56,57) and AQUASTAT (3). Its global applicability and integration with dietary data dissemination platforms such as FAO/WHO GIFT underscore its importance in promoting sustainable food systems. Future applications of the IDEA can further aid understanding the environmental implications of dietary choices and support the development of policies that encourage healthy diets from sustainable food systems.

DISCLAIMER

The views expressed in this publication are those of the author(s) and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations.

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AUTHOR CONTRIBUTIONS

Conceptualization, JTS, VPQ, XSR and CR; Methodology, JTS, VPQ and CR. Validation: JTS, VPQ, AB; Formal Analysis, JTS; Resources, JMFG, AF, AK and DR. Data Curation, JTS, VPQ, BT and CR. Writing – Original Draft, JTS and VPQ. Writing – Review & Editing, JTS, VPQ, JMFG, BT, AB, AF, AK, DR, XSR, BAH, CR. Supervision, BAH and CR.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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