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The “SQUIID claim”: A novel LCA-based indicator for food dishes

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ABSTRACT

Many studies aimed at estimating the environmental impacts associated with the food sector, but most of the existing developed indicators limited the problem only to the climate change, while it is well-known that the food sector may extend its influence on a wider spectrum of environmental categories. In this work, the Life Cycle Assessment was applied to a list of 1001 recipes for an Italian food canteen, prepared with more than 150 ingredients, with the purpose to develop a comprehensive environmental indicator (namely, SQUIID: Simplified Quantitative Impact Indicator for food Dishes). SQUIID includes in the evaluation the environmental categories showing a significant contribution (at least 86%) to the single score, i.e., global warming potential (GWP), particulate matter formation, land occupation, human non-carcinogenic toxicity and water consumption. The list of recipes was then analyzed under three perspectives: mass, GWP and SQUIID. The mass perspective indicates that the list of recipes contains a fairly balanced amount of ingredients, pointing out a remarkable diversification of the menu in the examined canteen. Concerning GWP and SQUIID spheres, meat-based and fish-based recipes resulted the main impacting ones (77% for the former and 73% for the latter), demonstrating to be the two classes mainly responsible for the environmental impacts observed, even if the vegetarian and vegan food dishes represent the 41% in mass. Meat-based dishes represent the 42% of the entire list of recipes in case of GWP, when adopting SQUIID, their overall contribution is reduced to the 35%. In fact, the main percentage of SQUIID is instead attributed to fish, raising from 31% (GWP) to 43%. Such variation demonstrated the relevance of the four additional selected categories for a final and comprehensive evaluation, proving that GWP-based indicators provide to the consumer only a partial representation of the environmental issue.

1. Introduction

1.1. The need for sustainability in the food sector

Food sector sustainability transversally links to many social, health and environmental concerns so that the transition towards more sustainable food value chains represents one of the greatest challenges worldwide (Mancini et al., 2023). A global interest in this topic is also mainstreamed by the United Nations in the “2030 Agenda for Sustainable Development”, which calls for overarching actions and spurs countries to end hunger through a sustainable management of natural resources, promote responsible consumption patterns and climate mitigation interventions (UN, 2015).

However, the spreading of initiatives and policies aimed at optimizing the food supply chain and to reduce food waste is challenged by increasing food demand and world population, with the latter one being expected to reach 9.7 billion of inhabitants in 2050 (UN, 2019). In addition, the intensification of agricultural practices (FAO, 2014) determines a dual effect in the climate crisis: on the one hand, the agrifood industry is estimated to release about 24% of annual global greenhouse gases (GHG) in the atmosphere, while on the other hand extreme weather events induced by global warming may affect crop yields, food prices and availability (EEA, 2017; EPA, 2017; Vermeulen et al., 2012), ultimately causing crises and reducing the capability of natural ecosystems to sustain the food demand (Lipper et al., 2014; Wheeler and Von Braun, 2013).

In the recent years, this issue has gained growing importance in the public debate: increased consumer awareness of ethical concerns such as animal welfare, child labor and, in particular, environmental sustainability has led to greater willingness-to-pay for more sustainable food products (Rousseau and Vranken, 2013; Vanhonacker et al., 2013), and drives consumers’ purchases nowadays as much as price, cultural behavior, health considerations, convenience, and sensory appeal (Hasselbach and Roosen, 2015; Hauser et al., 2011; Lusk and

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Briggeman, 2009; Lyerly and Reeve, 2015; Pula et al., 2014). Notwithstanding this, several studies have highlighted a divergence between the ethical sensitivity of the end users and a real environmental sustainability of their choices during the purchase of food. Such discrepancy is due to several reasons including our wrong perception of the hidden environmental impacts in food supply (Osman et al., 2021; Peschel et al., 2016; Tobler et al., 2011; Vlaeminck et al., 2014), an attitude-behavior gap of consumers in making little use of front-of-package labels during food purchasing (Grunert et al., 2014; Lazzarini et al., 2018; Temple, 2020; Vermeir et al., 2020), as well as a lack of exhaustive and widely accepted assessment schemes. These challenges amplify for food purchased in catering venues such as self-service canteens, where often no information about the environmental impacts of meals is available.

1.2. Analysis of the relevant literature

In the last decades, many research works have estimated the impacts associated to food production, with most of the existing indicators for aliments being framed onto life cycle assessment (LCA) methodology. The possibility to determine the potential environmental impacts associated to goods, services, or systems over their life cycle makes LCA a preferable methodology to develop metrics and indicators for food (Bulle et al., 2019; EPD search, 2020; Huijbregts et al., 2017; Verones et al., 2020), eventually combined to health or social dimensions (Petit et al., 2018).

For instance, Eco-score® (ADEME, 2021) is a French initiative developed to rank food products from A (low) to E (high) scores according to their impact onto the environment. Eco-score® builds upon AGRIBALYSE® (Koch and Salou, 2015) inventory data and expresses LCA-based results in millipoints (mPts) per kg of product, then scaled onto a value between 0 and 100. The obtained 0–100 scores are then adjusted with additional indicators (AddInds) arbitrarily assigned and aimed at “capturing the environmental issues that are considered to be not properly represented and accounted in the LCA model”, which include: *i)* the production system, *ii)* the local procurement, *iii)* the circularity of packaging, *iv)* environmental policy, and *v)* threatened species (ADEME, 2021). Bonus and/or malus (B/M) can be then added to each item, influencing the final score. For instance, assuming to be in the worst case of 100 points calculated by the LCA score scaling, the AddInds might alter the scaled value up to the 40% while, assuming to have a baseline value of 50 points obtained by the LCA, the alteration may potentially reach the 80%, giving a very relevant role to external adjustments.

In addition, examining the AddInds some further critical considerations can be drawn. First, the AI of production system is aimed at distinguishing the conventional and the organic production, especially referring to the impacts on ecosystem and biodiversity of the phytosanitary products (water, in particular) (Colruyt group, 2021). The issue is not attributed to the impact methods, which are developed to account for environmental effects of an activity on the biodiversity (Bulle et al., 2019; Huijbregts et al., 2017; Verones et al., 2020) but rather, to the absence of appropriate and exhaustive information in the database (AGRIBALYSE®), since the inventory of the organic products is described only for a limited number of them (e.g., beef, beer, chicken, flour, eggs and some varieties of fruit and vegetables). This lack is compensated by the attribution of mentioned B/M in relationship to the certifications or labels assigned to the foods, but this decision could mislead the issue, since the environmental benefits given by the organic production are currently object of discussion (Coppola et al., 2022; Foteinis and Chatzisymeon, 2016; Meier et al., 2017; Notarnicola et al., 2017; Verdi et al., 2022). For instance, conventional and organic production of carrots are responsible of an emission of 0.063 CO_2 eq/kg and 0.092 CO_2 eq/kg, respectively. Similar discrepancies result for eggs (1.57 CO_2 eq/kg and 2.04 CO_2 eq/kg) and pork meat (2.45 CO_2 eq/kg and 4.27 CO_2 eq/kg). This is partially due to the larger surface of land needed to produce the same amount of food, reflected also in wider distances traveled by the agricultural machineries (Notarnicola et al., 2017; Wernet et al., 2016). The trend is reversed for some items like beef or flour where, in comparison with the conventional, impacts of the organic production are instead lowered of the 12% and 38%, respectively.

For AddInd related to local procurement, B/M are basically associated to the modality and distances of the product transportation and supply chain. This AddInd is proposed to deal with another database lack, since AGRIBALYSE® provides transport information referring to an average transportation modality (e.g., road, water, etc.) and distance. The main idea was to use the B/M values to reward foods travelling lower distances, even if the LCA methodology allows to include the correct transportation information in the counting, making this AddInd unnecessary.

The AddInd related to circularity of packaging is another topic widely debated in the literature (Karayılan et al., 2021; Kleine Jäger and Piscicelli, 2021; Marrucci et al., 2022). Variables such as recyclability, reduction of packaging weight, recycled content, etc., are considered as poorly represented in LCAs. Bonus are generally attributed to items which show a “high recyclability”, but it does not necessarily represent a low environmental impact (Licciardello, 2017). Moreover, the packaging step is estimated to contribute for less than the 10% of the total environmental impact of a food product (Kan and Miller, 2022; Poore and Nemecek, 2018) and, exactly as for transportation, it could be properly included in the LCA model. An additional subject of considerable concern is the release of microplastics resulting from improper packaging management (Coralli et al., 2022). In this context, efforts are underway to develop characterization factors that can take into account these aspects (Corella-Puertas et al., 2023).

The environmental policy AddInd, aimed to capture variables related to the location of production (discharge standards, electricity production, biodiversity, etc.), is probably one of the most challenging factors to be included into consideration due to country specific requirements. However, model adjustments can solve this issue: as an example, electricity mix can be adapted to geographical contests. Similarly, although threatened living species are properly characterized in most of the recent LCIA methods (Bulle et al., 2019; Huijbregts et al., 2017; Verones et al., 2020), they are yet accounted by dedicated AddInd in Eco-score®.

Another initiative has been launched by Barilla Center for Food and Nutrition, which proposed the Double Pyramid Model (DPM), a very clear representation which demonstrates how foods that are recommended to be consumed most frequently are also those exerting the lowest environmental impact (Ruini et al., 2015). DPM is based onto LCA and but it focuses only on carbon footprint, water footprint and ecological footprint, excluding other impact categories.

A further recent example of indicator was proposed by Volanti et al. (2022), who developed a carbon footprint/food energy index for school canteens. However, also this indicator considers only GHGs emissions. Finally, another indicator has been proposed by the Environmental Working Group indicator (EWG, 2014), which aims is to provide an index based on nutritional, ingredients and processing. It is not structured on the LCA methodology and consists in arbitrary additions of B/M as function of several factors. The mentioned proposals are already available on the market and represent only a portion of the wide number of existing initiatives. To summarize, it emerges the need of LCA models and food environmental indicators that would allow for accurate, overarching, and transparent estimation of the environmental impacts of food. The lack of transparency could imply the mistaken interpretation of life cycle phases such as packaging or transportation, which may not necessary account for most of impact. Furthermore, factors such as production practices (organic, biodynamic, or other technologies) should be incorporated into the calculation rather than provided as additional information since a proper LCA model can readily assess the environmental impacts associated with such practices. From the brief review on sustainability assessment methods and indicators for food it emerges that most attention have been focused on implications for GHG emissions and climate change (Clune et al., 2017; Dong and Miller, 2021; Ulaszewska et al., 2017; Volanti et al., 2022; Weber, 2021). However, the nexus between the food sector and the environment extends further beyond the climate emergency and comprehends other key Earth system components and processes such as the exploitation of the natural capital, with inputs of water (García-Herrero et al., 2023), land, and energy being potentially responsible for negative consequences onto soil degradation, water scarcity, and air pollution (Ivanova et al., 2016; Poore and Nemecek, 2018). For instance, Poore and Nemecek (2018) estimated that food production is responsible for about 32% of global impacts on terrestrial acidification, 78% on eutrophication and that up to 95% of global water scarcity is due to irrigation operations. It implies that the adoption of a single-issue approach (e.g., carbon footprint) is not appropriate in LCA, since the impact categories shall reflect a comprehensive set of environmental issues related to the product system under investigation (Cespi et al., 2016; ISO, 2006a). For this reason, impact assessment methods covering a broader range of impact categories should be generally preferred.

On the other hand, the need to consider an appropriate selection of impact categories often contrasts with the possibility of communicating the results in an understandable and adequate way to the public (Cespi et al., 2016), which does not always have full knowledge of the environmental mechanisms behind the cause-effect chain between environmental stressors (e.g., emissions, natural resource consumption) and their impact or damage on the ecosystem and the human health.

Some life cycle impact assessment (LCIA) methods include normalization and weighting factors to further elaborate the characterization results and enable their aggregation in a single score or a smaller number of endpoint categories (Bulle et al., 2019; Huijbregts et al., 2017; Verones et al., 2020), but defining an objective weighting procedure that enables comparison between different impact categories remains one of the main challenges in LCA (Bulle et al., 2019; Huijbregts et al., 2017; Rosenbaum et al., 2008; Van Zelm et al., 2009; van Zelm et al., 2007; Verones et al., 2020). In particular, this is a primary need when the goal is to reduce the number of significant environmental impact categories (Steinmann et al., 2016) or develop an indicator that is as much concise as possible but which preserves the essential information (Galindro et al., 2019; Vizzoto et al., 2021).

To this aim, here we apply LCA to a list of recipes (LoR) prepared with more than 150 ingredients by the Italian food catering company CAMST - Soc. Coop. a.r.l. (CAMST) for a self-service canteen to estimate the environmental profile of daily meals and determine the contribution of different ingredients to the total impact. The LoR corresponds the actual menu served by the CAMST company in the year 2021. The choice was made in agreement with the company, deeming it representative for both the local context and the national context, since restoration companies are asked to follow common national guidelines for the menu proposals (SINU, 2019). The outcomes were then further elaborated to develop a ReCiPe-based (Huijbregts et al., 2017) single score indicator that synthetizes the environmental impact into a subset of the most significant impact categories, ultimately providing a novel index that support food producers that wish to include environmental assessment in their product portfolio as well as food consumers for conscious choices.

1.3. *CAMST food catering company*

Founded in Bologna in 1945, CAMST is one of the earliest established and largest food catering companies in Italy (Camst - Soc. Coop. a.r.l., 2022). It produces about 65 million meals annually, provided to both commercial food services. Over the years, the company has expanded in Europe and it is now present in Spain, Denmark, Germany and Switzerland, counting on more than 2000 commercial exercises. This study is performed in collaboration with the company, which supported data collection for life cycle modelling and shared information about the recipe composition of a common self-service canteen in Italy, characterized by a certain number and types of meals that compose daily menus, selected in according to several criteria including the targeted customers, nutritional balances, and seasonality of food.

2. Materials and methods

2.1. *Life cycle assessment*

LCA is a well-established and standardized methodology for the estimation of environmental impact of products, processes, or systems throughout their entire life cycle (ISO, 2006b, 2006a). The general LCA framework consists of the following conceptual phases, namely goal and scope definition, life cycle inventory (LCI), and life cycle impact assessment (LCIA), which applies environmental mechanisms and characterization models to relate the LCI results to selected category indicators for a quantitative evaluation of environmental impacts. A fourth phase, interpretation, is transversal to the previous ones to guarantee consistency between the aims of a study and its execution and finally structured to draw recommendation. In the next paragraphs, the four phases are described with reference to the system under investigation.

2.2. *Goal and scope definition*

The aim of the study is to *i)* develop a LCA dataset for the LoR provided by the company in the self-service canteen; *ii)* elaborate a single score indicator (i.e., SQUIID), for providing essential environmental information to the stakeholders (company staff and customers) of the self-service canteen under scrutiny; *iii)* compare the relevance of each ingredient among the entire LoR in terms of mass, GWP and SQUIID, with the purpose of identifying the most impacting ingredients and to provide a scientific base to suggest more sustainable alternatives; and *iv)* put the basis for the development of an environmental indicator adaptable to different activities connected to the food industry. The SQUIID framework is then described in section 3.3. The first task was to estimate the environmental impacts of the food ingredients from the company LoR. The LoR is constituted by 1001 food dishes, based on 151 different ingredients available for meal assembly. To this aim, in line with previous studies in the relevant literature (Kägi et al., 2016; Volanti et al., 2022), it was decided to select "one single food dish provided" as functional unit (FU). Since the food dishes are assembled in compliance with the recommended nutritional guidelines (SINU, 2019), the choice of such FU is aimed to indirectly include the nutritional variables into the final evaluation (Batlle-Bayer et al., 2021; Mcauliffe et al., 2020).

The system boundaries (Fig. 1) applies a *cradle-to-kitchen* approach, including –if applicable–infrastructure and machineries employed for food production and supply, cultivation, farming, food processing (e.g., slaughtering, peeling, etc.), packaging, transportation and food storage/preservation. It was decided to exclude the cooking stage from the model due to lack of data on the type of equipment used in kitchen as well as material and energy balances associated to the cooking phase of each food product. Moreover, previous studies have indicated that the cooking phase, which closely depends on the technology of the equipment (e.g., electric or gas ovens), the cooking time, and also the discretion of kitchen staff (Hager and Morawicki, 2013; Pathare and Roskilly, 2016) generally contributes to less than 8% to the overall impact (Mistretta et al., 2019).

2.3. *Life cycle inventory (LCI)*

The LoR was provided by CAMST, which extracted the entire dataset of primary information from its Enterprise Resource Planning. Full list is collected in Table S1, reported in the Electronic Supporting Material (ESI). The list contains 1001 recipes and is composed of 151 ingredients. According to the ingredient composition, the recipes were clustered in 4 sub-types of meals, namely: *i)* meat-based meals (43% of the total); *ii)*

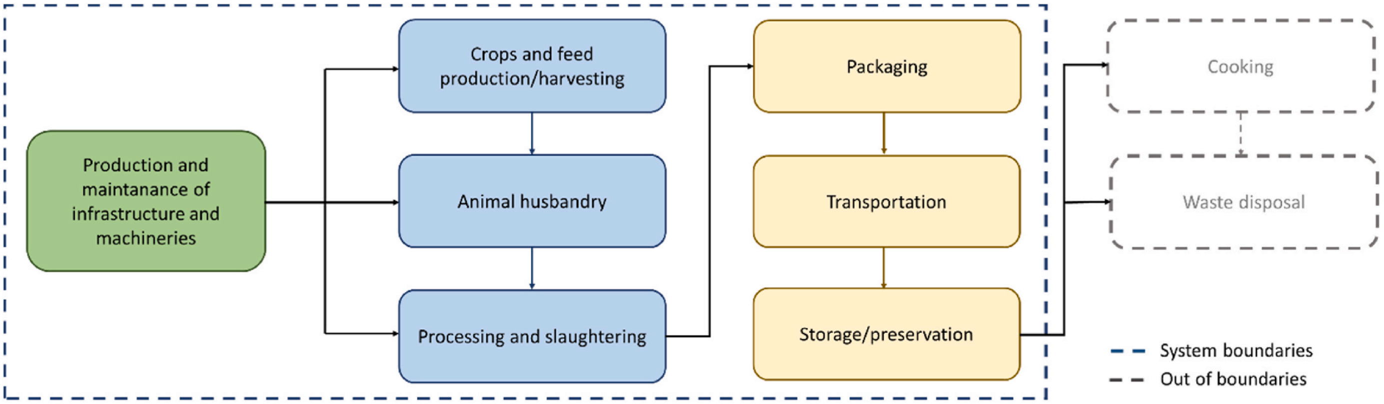

Fig. 1. System boundaries from cradle to kitchen. The green box represents infrastructure and food production machineries, blue boxes represent the "food production phases", while yellow boxes are referred to packaging, transportation and storage. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

fish-based meals (16%); *iii)* vegetarian meals (26%); *iv)* vegan meals (15%). Recipes containing both meat and fish ingredients were assigned to the sub-type of the ingredient (meat or fish) present in the greatest amount. To simplify the data collection, a cut-off criterion was applied to exclude the ingredients contained in recipes for less than 1% of total mass (e.g., salt, spices), approach allowed by the ISO and in line with the product category rules used in environmental product declaration (EPD) label for food (EPD search, 2020). LCI of the ingredients covered in the analysis is based on the AGRIBALYSE® 3.1 (Koch and Salou, 2015) and ecoinvent 3.7 (Wernet et al., 2016) databases, which provides dataset for the average ingredients on the EU market and are assumed to be a consistent approximation with the system under scrutiny. It is worth mentioning that material supply chain and market channels may differ from one country to another, in some cases. However, very often food production practices have similar characteristics regardless of the geographical area of reference (for example, the use of diesel as energy carrier for fishing vessels), also because of a globalized food market. In this sense, although site-specific data would increase accuracy of LCA models, some more general considerations can still be advanced for stakeholders and policymakers, as we further comment in the text. The databases are accessed with the SimaPro 9.4 (PRé Consultants, 2022). This software is considered one of the most comprehensive and widely used in the field of LCA and allows the visualization of the network of processes associated with the final product, enabling the identification of the contribution to the final impact value of each process or material involved in the product-chain. The environmental values per 1 kg of item are reported in Table S2 of the ESI.

2.4. Life cycle impact assessment (LCIA)

The LCIA method selected for environmental impact assessment of the company recipes is ReCiPe 2016; Huijbregts et al. (2017), which includes in the evaluation 17 environmental impact categories, i.e., Particulate matter formation potential (PMFP), Global warming potential (GWP), Stratospheric ozone depletion potential (ODP), Ionizing radiation potential (IRP), Tropospheric ozone formation potential (OFP), Tropospheric ozone formation potential (ecosystem, OFP), Terrestrial acidification potential (TAP), Freshwater eutrophication potential (FEP), Marine eutrophication potential (MEP), Freshwater ecotoxicity potential (FETP), Marine ecotoxicity potential (METP), Human toxicity (cancer, HTPc), Human toxicity (non-cancer, HTPnc), Land occupation potential (LOP), Mineral resources depletion potential (SOP), Fossil resources scarcity potential (FFP) and Water consumption potential (WCP). The choice is principally motivated by the high diffusion of the method in the relevant literature (Deeney et al., 2023; Lamnatou et al., 2022; Miniakhmetova et al., 2022), its inclusion of an overarching selection of midpoint impact categories, and the fully transparent characterization, normalization and weighting mechanisms from midpoint to endpoint results (Table S3 in ESI). In addition, the method allows the adaptation of the study to the analyzed context by selecting a proper perspective (i.e., egalitarian, individualistic, hierarchical). In our case, the hierarchical perspective was adopted for the specific case study, being considered as main representative for the society in which the evaluation is provided. More details about the selected categories are described in 3.1.

3. Results and discussion

3.1. Life cycle assessment selection of the categories

In Fig. 2 a comparison of the LCIA results for the four clusters described above is shown. Box plots shows values for average, 1st (25%) and 3rd (75%) quartiles of the long-tail distribution of impact assessment results for the set of dishes investigated. In general, the meat- and fish-based dishes rank as more impacting than vegetarian and vegan dishes. Meat-based dishes have the highest average impact for 13 out of 17 impact categories, including GWP, ODP, IRP, TAP, FEP, MEP, FETP, METP, HTPc, HTPnc, LOP, SOP, and WCP. Fish-based dishes follows for the remaining four ones (i.e., OFP, PMFP, TETP, FFP). When meat-based dishes usually rank at 1st place, fish-based dishes rank at 2nd and vice versa, with the exception of ODP, IRP, and LOP for which vegetarian dishes are the second-most impacting family class.

It is worth noting that the family class with the highest average impact for a given category does not necessary match with the most distributed family class for that category. For instance, meat-based dishes are more distributed than others for only 7 of the 13 categories in which resulted to have the highest average impact (GWP, ODP, IRP, TAP, HTPnc, LOP, and SOP). In all the remaining impact indicator, fish-based dishes result as the most distributed family class.

Meat- and fish-based dishes have generally similar distribution ranges, while vegetarian and vegan food dishes for certain categories (GWP, OFP, PMFP, TAP, FFP) have dispersion of up to one-order magnitude less than the formers. In a few cases, the dispersion gap between family classes is significant, with fish-based dishes showing very long tails for FEP, MEP and WCP, while dispersion of meat-based dishes is dominant for ODP and LOP. Overall, the single score results confirm the higher impact for meat-based and fish-based dishes than vegetarian and vegan ones, with the former two classes being attributed to have similar average impact value and dispersion. In Fig. 3, the percent contribution of individual impact categories to the end point single score is showed (scree plot on the left-hand side panel, cumulative on the right-hand side). The results are presented by family class, after

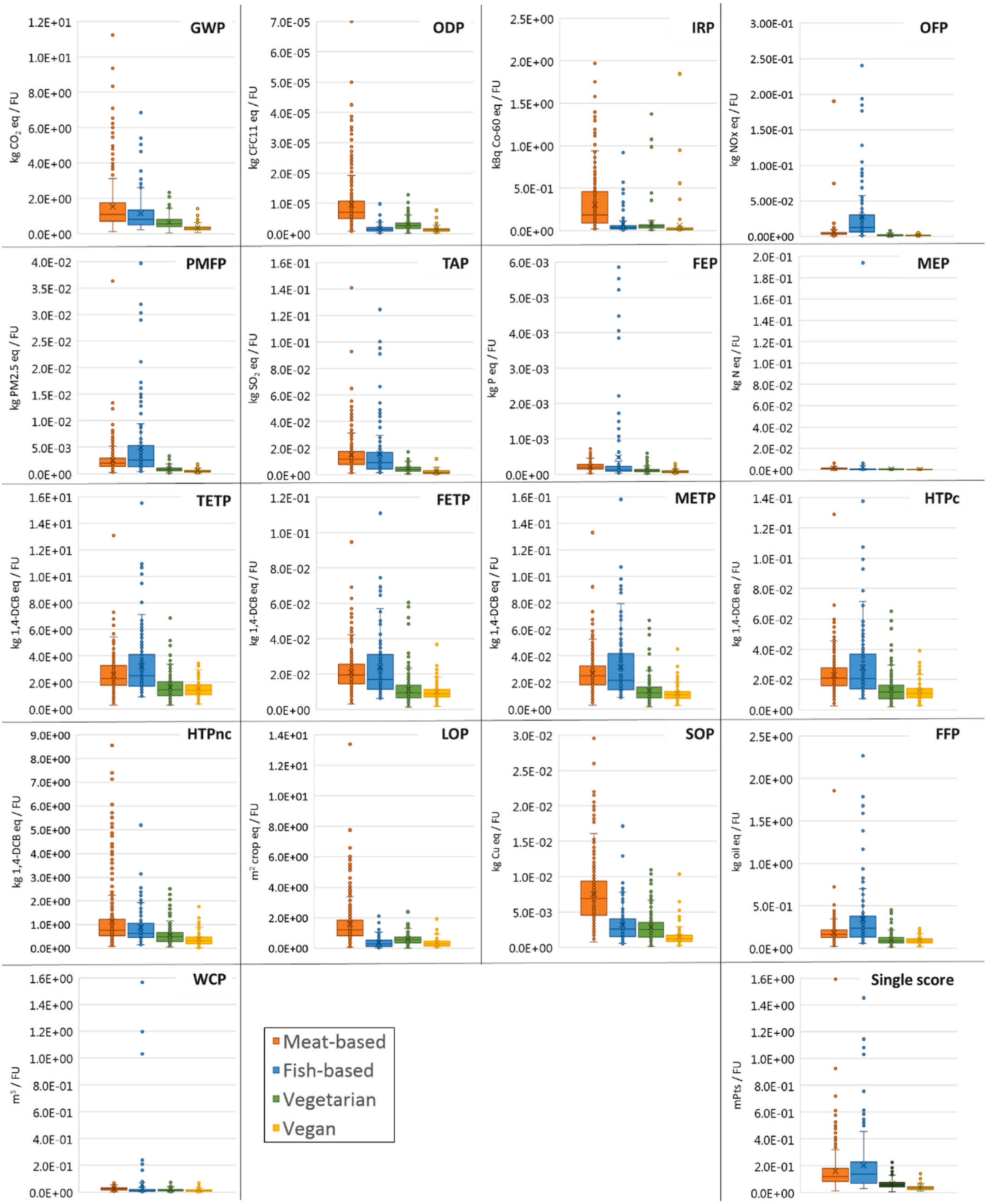

Fig. 2. Box plot representing the GWP, ODP, IRP, OFP, PMFP, TAP, FEP, MEP, TETP, FETP, METP, HTPc, HTPnc, LOP, SOP, FFP, WCP and single score of the LoR.

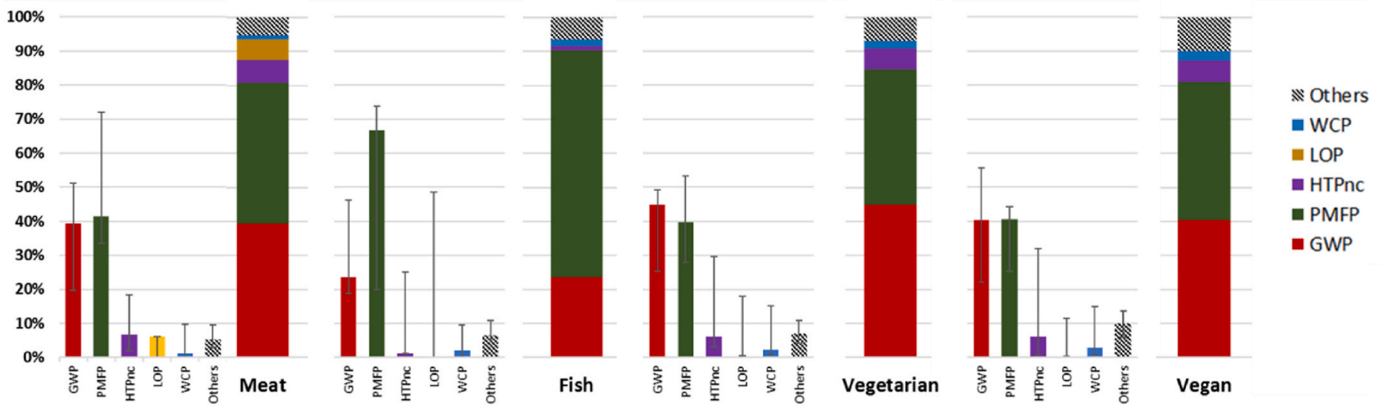

Fig. 3. Contribution of selected environmental categories on the 5 selected impact categories per food class.

normalization and weighting of LCIA results. A detailed table of contribution is reported in ESI (Table S4).

It is worth noting that top-five impact categories are common to all the family classes, with GWP and PMFP contributing for more than 80% of the total impact, on average. The relative shares of GWP and PMFP are similar for meat-based, vegetarian and vegan, while for fish-based a higher contribution is attribute to PMFP. If HTPnc, LOP and WCP are also included, total rate achieves 86% at least, while the remaining impact categories grouped under a generic “others” label contribute a maximum of about 14%.

The outcomes in Fig. 3 suggest that GWP, PMFP, HTPnc, LOP and WCP impact categories should be prioritized when assessing the environmental impact of food. More specifically, the highest average contribution to the single score is estimated for PMFP (42.0%), followed by GWP (36.4%), HTPnc (7.4%), LOP (5.3%) and WCP (2.1%). The remarkable PMFP value associated to caught fish based products is mainly attributed to diesel combustion during fishing operations (from 50% to 75% of total PMFP impact) in line with the findings of Koch and Salou (2015), while in the case of farmed fish the impact shifts to the farming stage (Sandison et al., 2021; Wernet et al., 2016; Ziegler and Hilborn, 2023).

Although HTPnc, LOP, and WCP categories show a lower average contribution to the single score than GWP and PMFP, they are not negligible since, for some recipes, their contribution is estimated to reach about 30% of total impact (e.g., quinoa salad, valerian salad, bell peppers, almonds and pistachio-almond cake). HTPnc, in particular, shows high values in foods containing almonds because of the intensive use of fertilizers, which may determine significant zinc release to the soil during use (Koch and Salou, 2015; Wernet et al., 2016). WCP is mainly influenced by water consumption in the farming phase (Koch and Salou, 2015; Wernet et al., 2016), while LOP has higher percentages (around 15%) in some legumes such as chickpeas, beans, and peas (Wernet et al., 2016). Accordingly, the exclusion of any of these three categories, would mislead part of the issue for some foods, providing incomplete information.

3.2. The influence of single ingredients on the environmental impacts

In Fig. 4, the single ingredient contribution on the total mass of the ingredients present in the LoR (Fig. 4a), GWP (Fig. 4b) and the Simplified Endpoint Single Score (5-EPSS), which represente a single score constituted by GWP, PMFP, HTPnc, LOP and WC (Fig. 4c), are calculated for the four food classes. For instance, pork meat is used only in meat-based recipes so that 100% mass contribution is attributed to that ingredient, while fresh tomatoes are used for 28% in meat-based recipes, 20% in fish-based, 26% in vegetarians and 26% in vegans (Fig. 4a). In the same way, 27% of the GWP impact of fresh tomatoes is associated to meat-based recipes, 20% to fish-based, 26% to vegetarians and another 26% to vegans (Fig. 4b). The same approach is applied to 5-EPSS (Fig. 4c).

On a mass basis (Fig. 4a), it is possible to observe that there are not ingredients which preponderantly prevail onto the others. The most employed ingredient is pork meat (5.5% on the total), followed by fresh tomato (5.2%) and dried pasta (5.1%). The first fish ingredient ranks in 19th position, with a percentage contribution of 1.5%. In contrast, from Fig. 4b it is evident that GWP is extremely influenced by meat ingredients, which are responsible for about 55% of the total GWP impact (and comprising 24.9% beef meat, 16.8% pork meat, 7.0% chicken meat, and 6.3% other meat), despite their mass contribution to LoR accounts for only 13.6%.

However, including in the analysis PMFP, HTPnc, LOP and WCP, the rank of the estimated impacts of ingredients is sensibly influenced. For instance, switching form GWP to 5-EPSS the relative contribution of meat decreases from 54.3% to 46.2% in favor of other ingredients, mainly fish (which instead increases from 11.0% to 19.0%), highlighting the need of overarching environmental assessment indicators. In this view, cod is exemplary as it ranks as 7th impacting ingredient for GWP (contributing to the 3.5% of the total) to be the 4th in the 5-EPSS list (6.2% of the total).

Fig. 4d depicts the 5-EPSS values per kilogram of ingredient. Single ingredient contribution to the 5-EPSS could support nutritional considerations by identifying target ingredients (I_{target}) which could be entirely or partially replaced to decrease the whole impact of the LoR. For instance, hypothesizing the substitution of a I_{target} identified in Fig. 4c (i.e., beef meat, pork meat, chicken meat and so on) with an equivalent amount of an alternative ingredient taken from the resting 149, it is evident that beef meat could be potentially replaced with everything but lamb meat (Fig. 4d). The task is more challenging for pork meat, which should not be eventually replaced by none of all the ingredients ranked above it in Fig. 4c (e.g., lamb, beef, blue shark, cod, golden fish, john dory, nurse hound, beans, dry ham, veal, butter and almonds). In case of chicken meat, the substitution would be even more challenging since, to those listed above, squid, bass, perch, mortadella, tuna, almond cake, grouper, snapper, swordfish and cooked ham are added. It is worth noting that the consideration of the single GWP as representative category, would induce the substitution of veal or dry ham with cod, bringing to a paradoxical opposite effect to the final aim. In addition, supposing to have the intention of replacing the identified I_{target} with an ingredient external to the 150 items (i.e., cultivated meat, Sinke et al., 2023), it is possible to apply the model to new or upcoming different market alternatives.

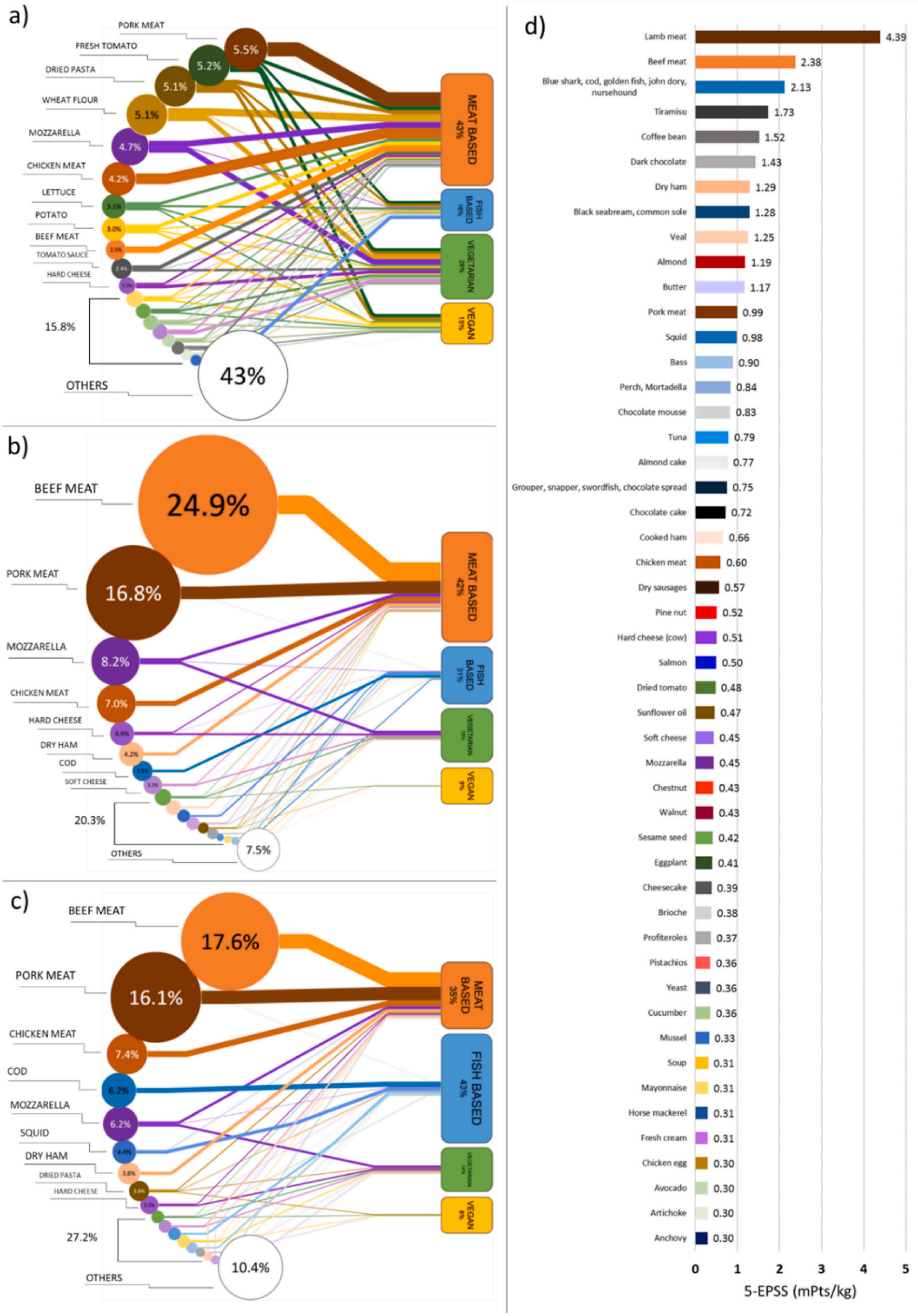

Fig. 4. a) Contribution of each ingredient to the total mass of the LoR; b) Contribution of each ingredient to the total global warming potential; c) Contribution of each ingredient to the total 5-EPSS; d) ranking of the ingredients based on their 5-EPSS value per unit of mass.

3.3. Development of a new environmental indicator for food dishes

Some important considerations can be drawn from the findings of the previous paragraph. First, the selection of additional impact categories may be very relevant in assigning an average environmental preference to the classes, confirming the need of adopting overarching LCIA methods. Moreover, limiting environmental considerations only to GWP would neglect significant complementary information and lead to partial view on environmental impacts of food (Fig. 3). As an example, while based on GWP results one could attribute to a fish item apparent environmental preference compared to other food categories, the same item turns to be the worst if PMFP is instead considered.

However, the average preferences depicted in Fig. 3 may not be sufficiently representative of the variability that characterizes a class and, therefore, of the highest impact values that classes can assume in a given category. In particular, this demonstrates how the comparison between classes of different diets does not always have a clear “winner”, but rather the analysis should be conducted on specific ingredients reiterating the necessity to support consumers for informed choices about which categories are the most significant and which dishes are the most (or the least) environmentally sustainable. The normalization and weighting of the characterization results to the single score allowed to tackle these issues.

According to Fig. 3, the most impacting 5 midpoint categories on the ReCiPe single score are selected for the calculation of 5-EPSS. The reduction of the number of categories leaded to a synthetic but representative set of environmental implications. Accordingly, the 5-EPSS was calculated for the all the food dishes of the LoR and the outcomes were further elaborated to develop a new simplified quantitative impact indicator for food dishes (hereafter, “SQUIID”) in three steps.

First, for each ingredient, 5-EPSS$_i$ (in mPts/kg) is computed as sum of the most impacting 5 midpoint categories, namely GWP$_i$, PMFP$_i$, HTPnc$_i$, LOP$_i$ and WCP$_i$ (Equation (1)).

$$5EPSS_i\ (mPts) = (GWP_i + PMFP_i + HTPnc_i + \mathrm{LOP}_i + WCP_i) \tag{1}$$

Second, for each food dish the *5-EPSS$_i$* score is multiplied by the amount of ingredients (m_i), as dictated by the company recipe, allowing to estimate the cumulative *5-EPSS* of each meal (*5-EPSS$_m$*, Equation (2)).

$$5EPSS_m\ (mPts) = \sum_{n=1}^{\infty} (m_i * 5EPSS_i) \tag{2}$$

Then, the *5-EPSS$_m$* values are scaled into a 0–10 interval, where 0 corresponds to the lowest environmental impact and 10 to the highest one. The distribution of the scaled value depicted in Fig. S5a makes it evident that the lognormal-like distribution would result in about 95% of the recipes ranking with a final score between 1 and 2 in the end. A log transformation is hence applied to the *5-EPSS$_m$* before being scaled into a 0–10 interval and result in the SQUIID (Fig. S5b).

Then, the maximum and minimum thresholds of SQUIID were consistently set to be the highest and the lowest *5-EPSS$_m$* values multiplied by a corrective factor to avoid extreme scores for environmental impacts (i.e., 0 or 10) which might be misleading for a consumer (for instance, SQUIID = 0 might be interpreted as “no environmental impact”). The corrective factors applied were respectively 1.05 and 0.95 for the highest and the lowest *5-EPSS$_m$* values in the dataset. The correction factors are based on the work by (Kovacevic, 2011).

$$SQUIID_m = \frac{\log(5EPSS_m) - \min\left[log(5EPSS_m)\right] * 0.95}{MAX[log(5EPSS_m)] * 1.05 - \ min[log(5EPSS_m)] * 0.95} \tag{3}$$

By looking at the single score plot of Fig. 2, different average SQUIID results occur by food class. In particular, vegetarian and vegan meals are generally characterized by lower values (3.82 e 2.98, on average), but some exceptions apply such as “grated fennel” (SQUIID = 5.36), enforcing the need of a food indicator since the knowledge of the food class may be not sufficient to have a representative information about the environmental impact of food. In this sense, SQUIID can provide a succinct, but representative quantification of the environmental impacts of food dishes to the consumers by employing only 5 of the 18 impact categories covered in ReCiPe 2016. In addition, it is worth noting that GWP, PMFP, LOP and WCP are also adopted by the Italian product category rules (RCPs) for cheese, meat and dried pasta (Ministero dell’ambiente e della sicurezza energetica, 2021a, 2021b, 2021c) and comply with the Italian minimum environmental criteria (MEC) developed for the restauration sector (Ministero dell’ambiente e della sicurezza energetica, 2020). GWP and WCP are also mandatory categories in the EPD program (EPD search, 2020). All of this to say that the diffusion of the selected categories could ease the comprehension of the customers. SQUIID values estimated for the LoR are reported in ESI 4.

3.4. Further improvements

The proposed framework for the development of SQUIID could serve as a reference for the formulation of other indicators developed for the food sector. The improvement of the proposed framework, but also its application to a specific context, can be pursed through two main paths: *i)* replacing the primary data of the LoR with site-specific information from the relevant context; and *ii)* utilizing information related to the food chain (eventually including also the cooking stage) and energy supply phases from databases compatible with that context. The latter aspect may constitute a main hindrance to future studies, since a more detailed knowledge of the ingredients’ supply chains information is likely lacking globally (Li et al., 2023; Sun and Wang, 2019). Potential benefits could derive by the development of national or regional datasets, following the example of ADEME (Koch and Salou, 2015). Despite these limitations, the proposed SQUIID framework might allow an accurate and easy-to-communicate estimation of the environmental impacts and the consequent preferability ranking of food dishes.

Finally, once a suitable framework for the application context is confirmed, the company might exploit the SQUIID information to identify and propose more sustainable food dishes. Then, canteens may communicate the SQUIID value to the consumer through various channels and modalities, including the use of a smartphone app, through the payment receipt, or by reporting it directly in the menu, in the food showcase, or in the website of the catering company.

4. Conclusions

The study offers a comprehensive and in-depth understanding of the environmental impact of various dietary choices within the context of self-service canteen. In particular, the LCA methodology is applied to develop an environmental indicator capable of accounting for the most significant environmental implications in the food sector. The key findings can be summarized as follows: *i)* Meat-based dishes are found to be the most impacting ones in 13/17 analyzed categories, while the remaining 4 are dominated by fish-based dishes; *ii)* Limiting the study only to the Global Warming Potential (GWP) provides only a partial perspective of the issue; *iii)* By selecting 5 specific environmental categories (i.e., GWP, fine particulate patter formation, water consumption, land occupation potential, and human non-carcinogenic toxicity, it was possible to capture 86% of the information contained in the single score and develop a new environmental indicator (named SQUIID); *iv)* It is not possible to predict a definitive ranking solely based on food class; instead, it is essential to thoroughly analyze the individual ingredients that compose each dish. It is worth mentioning that the 5 categories included in the SQUIID indicator are among the most known and used impact categories, a fact that might facilitate the communication to the public. For this reason, it is also adaptable for future expansions of recipe lists or for application in different contexts. Moreover, the SQUIID indicator should not necessarily be considered definitive but can serve as a track for the development of new indicators and the outcomes of this study can also serve as a reference point for further advancements in the field of environmental analysis within the food sector, with a specific emphasis on the 5 categories identified as crucial for a comprehensive assessment. Overall, the LCA methodology, demonstrated to be an essential tool for the evaluation of the environmental impacts of products and a promising option onto which develop metrics aimed at facilitating the interface between the consumer and the industry. Moreover, we believe that the obtained results may be informative for catering venues, food industries and communities.

CRediT authorship contribution statement

F. Arfelli: Conceptualization, Data curation, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. **L. Ciacci:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **D. Cespi:** Supervision, Validation, Writing – review & editing. **Vassura:** Conceptualization, Investigation, Supervision, Writing – review & editing. **F. Passarini:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

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.

Data availability

All the used data are attached in the supplementary material

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Appendix A. Supplementary data

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