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Sustainable Development and Planning XIII

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THIRTEENTH INTERNATIONAL CONFERENCE ON SUSTAINABLE DEVELOPMENT AND PLANNING

Sustainable Development and Planning 2024

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Conference Chairs

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Sustainable Development and Planning XIII

Editor

Stavros Syngellakis
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Preface

This volume contains edited papers presented at the 13th International Conference on Sustainable Development and Planning, organised by the Wessex Institute of Technology (WIT). This event took place in Seville, Spain from 23 to 25 September 2024.

The contributors to this volume addressed problems related to development and planning, affecting urban and rural areas, and encountered in many regions of the world. Accelerated urbanisation has resulted in the deterioration of the cities' environment and loss of quality of life. Developing new methodologies for monitoring current conditions as well as planning and implementation of novel mitigating strategies can offer solutions towards reducing pollution and the non-sustainable use of available resources.

Energy-saving and eco-friendly building designs have become an important part of modern development, which places special emphasis on increasing efficiency and reducing emissions. Planning has a key role to play in ensuring that such approaches, as well as new materials and processes, are implemented in the most effective manner.

Sustainability in the built environment is a broad area of study covered extensively in this volume with articles dealing with urban planning and design, shared and green spaces as well as sustainable building practices. The impacts on the environment are examined in the contexts of tourism, air pollution and greenhouse gas emissions, diesel to electric mobility transition as well as energy, sugar and bicycle helmet production.

Management strategies for wetlands and national forests, drought, water scarcity and desalination, seawater intrusion are some of the issues discussed under natural resources management.

Public views, the stock market as well as multidisciplinary dimensions and elements of green logistics are explored as the basis for possible sustainable development indicators. The analytic hierarchy process is applied to bridge the gap between aquavoltaics policy planning and stakeholder expectations. It is suggested that expressway construction has a moderating effect on environmental governance and sustained environmental, social and governance performance has an influence on corporate financial performance; also, that the sanctioning process in mining legislation can be strengthened by stakeholders' engagement.

The volume also includes plenty of informative and topical material in the areas of sustainable mobility, energy efficiency, community and city planning, rural areas development, waste management, quality of life as well as the carbon and ecological footprint.

Two special sessions were held at the conference. The subject matter of the first was strategies for environmental sustainability with focus on waste collection, treatment and disposal as well as environmental performance and practices in higher education institutions, in particular. The second special session was dedicated to energy-climate transition through transnational municipal cooperation. Papers from this session deal with adaptation planning for addressing climate change in urban environments as well as local and national authorities' strategies for clean energy transition.

These papers, like others presented at WIT conferences, are uploaded to CrossRef and appear regularly in suitable reviews, publications and databases, including referencing and abstracting services. They are also archived on-line in the WIT eLibrary (http://www.witpress.com/elibrary) where they are permanently available in Open Access format to the international scientific community.

The Editor wishes to thank the members of the International Scientific Advisory Committee who have peer-reviewed the submitted papers. Special thanks go to the Conference Coordinator, Ms Marta Graczyk, WIT's IT Manager, Mr Alan Morgan, and WIT Press Production Manager, Helen Hill, for their significant contribution to the success of the conference and the processing of papers for publication in these Transactions.

Stavros Syngellakis

The Editor, 2024

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NUTRITIONAL LIFE CYCLE ASSESSMENT: A PARADOX OR A PATHWAY TO SUSTAINABLE AGRO-FOOD SYSTEMS?

VALENTINA NICCOLUCCI[1], COSIMO MONTEFRANCESCO[1], ROBERTA RUSSO[1], ELISA B. P. TIEZZI[2] & NADIA MARCHETTINI[1]
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ABSTRACT
A comprehensive sustainability assessment of food products requires a framework that effectively captures the complex interplay between nutritional value and environmental impact, encompassing both planetary-health and human well-being. This dual focus is becoming increasingly relevant: it can happen that foods with exceptional nutritional benefits may still come with substantial environmental costs. Conversely, foods with lower environmental impacts might not offer optimal nutritional value. The challenge, therefore, is to achieve a balance between consuming foods that are both healthy and sustainable. Despite the extensive literature on the environmental impacts of food production and consumption – often assessed through life cycle assessment (LCA) – there remains a notable gap in integrating nutritional aspects into these evaluations. This paper aims to address this gap by exploring the application of nutritional life cycle assessment (n-LCA), an emerging tool designed to incorporate nutritional information into the traditional LCA framework. Given its novelty, this paper discusses both the potential benefits and limitations of n-LCA. A practical case study from a specific food group is presented to support this discussion, particularly in terms of selecting the most appropriate functional unit and highlights the importance of utilising such tools. The findings suggest that n-LCA provides a more holistic framework for evaluating food system sustainability, offering a deeper understanding of the trade-offs between health and environmental sustainability, and thereby facilitating more informed decision-making in food production and consumption.
Keywords: agri-food products, life cycle assessment, nutritional life cycle assessment, sustainable production, human and planet health, carbon footprint.

1 INTRODUCTION
Agriculture is a predominant economic sector in most nations worldwide, serving as a major consumer of natural resources and, consequently, as a significant contributor to environmental degradation. Over the past few decades, substantial efforts have been made to quantify these environmental impacts. Current estimates reveal critical associations, attributing 30%–40% of global contributions to climate change, 70% of freshwater consumption, 30% of primary energy use, and 30% of habitat loss to agricultural activities, which is a major driver of biodiversity decline [1], [2]. At the same time, the escalating global population necessitates increased agricultural production, thereby intensifying the environmental costs [3].

One of the greatest challenges of the coming decades is meeting the global nutritional demand while safeguarding the environment and reducing pressure on food resources [4]. In this context, accounting tools such life cycle assessment (LCA) play a fundamental role [5]–[7]. It provides a robust framework for understanding the environmental implications of agri-food products, identifying key areas of environmental concern and potential trade-offs, and supporting the development of strategies to mitigate negative impacts and improve overall performance [6]–[10]. One notable advantage of LCA is its ability to identify

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potential burden shifts between different life cycle stages and environmental impact categories [4], [11].

Traditional LCA is primarily focused on purely environmental aspects, documenting the health and state of the environment by analysing various indicators such as climate change, resource depletion, acidification, ozone depletion, and other relevant topics [11]. While this approach offers a comprehensive understanding of how different stages of a product's life cycle can affect environmental integrity, it does not account for the primary function of food – its nutritional value and health implications. This gap in traditional LCA methodologies underscores the need for complementary approaches, such as nutritional LCA (n-LCA), which aims to integrate nutritional parameters into the environmental assessment framework [12]–[17].

In the context of the agri-food sector, the primary biological function of food consumption is to meet the essential nutritional needs of the human body. This fundamental role has been articulated in various ways within the literature. For example, Cucurachi et al. [6] describe it as the ability to 'satisfy the need of the human body to be nourished', while other authors discuss food's role in 'inducing satiety' [18], both emphasising the importance of food in fulfilling basic physiological requirements. Similarly, Kyttä et al. [19] highlight this function as 'the adequate intake of energy and nutrients to maintain bodily functions and health' underscoring the necessity of a balanced diet to support overall well-being. McLaren et al. [20] concisely refers to this function as 'providing nutrients' capturing the essential role of food in delivering the vital substances required for growth, maintenance, and health. Moreover, food consumption patterns vary widely based on geography, gender, age, culture, customs, and social status, among other factors.

This paper offers an insight on the topic of n-LCA methodology highlighting its key features and its potential to address the complex challenge of balancing global nutritional demands with environmental resources supply.

Moreover, a detailed overview of the most suitable and informative functional units and impact categories for n-LCA studies is proposed. The importance of selecting appropriate functional units – whether mass-based, energy-based, or nutrient-specific – is emphasised, as these choices significantly influence the outcomes of LCA assessments, underscoring the need for careful consideration to ensure the accuracy and relevance of the analysis. Similarly, the selection of impact categories must be meticulously chosen to capture the full spectrum of sustainability considerations relevant to food systems.

To contextualise and support the theoretical discussion, this study includes an in-depth analysis of the 'oils and fats' food group. This empirical example demonstrates how n-LCA can be applied to evaluate the sustainability of different food systems. The ability to provide a nuanced understanding of how food production and consumption impact both planetary health and human well-being is essential, even though much progress is still needed in this topic.

The results presented in this paper were developed within the framework of the AGRITECH project, which is part of the Italian National Recovery and Resilience Plan (PNRR). This project focuses on a comprehensive evaluation of environmental, social, and economic impacts within food production chains. The primary aim is to enhance the sustainability of agricultural practices and food production by integrating innovative technologies and methodologies designed to assess and mitigate adverse impacts. In doing so, the project seeks to address the complex challenges associated with sustainable food systems, promoting practices that not only look at reducing environmental impacts but also include other perspectives such as economic and social, with a look also at the nutritional aspects.

2 MATERIAL AND METHOD

n-LCA represent a novel advancement of the traditional LCA aimed to provide a more holistic evaluation that goes beyond environmental impact, considering the nutritional value and its implications for human health [20]–[24]. A simplified workflow for n-LCA adapted from McAuliffe et al. [24], is illustrated in Fig. 1. This workflow outlines the fundamental steps involved in conducting an n-LCA, providing a streamlined overview of the process from defining the goal and scope of the study to interpreting the results. The iterative sequence for traditional LCA is reported in black lines, while the specificities for n-LCA are depicted in grey lines.

The figure serves as a guide for understanding how different stages of the n-LCA framework interact, highlighting the importance of accurately defining functional units, selecting appropriate impact categories, and systematically collecting and analysing data to assess the environmental impacts of food products based on their nutritional contributions. At least two key aspects, closely interconnected, are worth discussing in detail: the selection of the most relevant and informative functional unit(s), and the choice of the impact assessment methodology [20], [24].

The choice of the most appropriate and meaningful nutritional functional unit(s) (n-FU) is a critical step in the n-LCA [20], [21], [23]–[26] and is included in phase 1. Its selection is influenced by several factors, including the specific characteristics and intended primary function of the product, the nutritional requirements of the target population, and the overarching objectives and scope of the study. A well-chosen n-FU ensures that the analysis aligns with the true function of the product. Additionally, a clear and appropriate n-FU facilitates consistency in data collection and interpretation, which is essential for obtaining reliable and comparable results.

To date, there is neither a consensus nor standardised guidelines on the most reliable n-FU, even if some guidance on selecting it have been provided [20]. The literature presents various approaches, each with its own advantages depending on the context and goals of the study as well if the impact assessment is mid- or end-point. Typical examples of mid-point n-FUs are based on the *quantity or volume* of food, as outlined in ISO 14044 [27] and supported by several authors [9], [20].

These n-FUs, which are commonly expressed in terms of mass (e.g., kilograms) or volume (e.g., litres), provide a straightforward and widely applicable basis for comparing different food products. Such FU is particularly recommended in the ENVIFOOD Protocol [28]. The limit of this n-FU is that do not include nutritional information and do not look at the substitutionally of food.

Another widely recognised n-FU is the *serving size*, which reflects a standard portion size such as one banana or one cup of wine. Alternatively, the *average daily intake*, such as the recommended dietary allowance (RDA), offers a more individualised FUs based on nutritional recommendations. Poore and Nemecek [4] highlight these approaches as meaningful ways to evaluate food products, as they align more closely with actual consumption patterns and dietary guidelines. These are dependent to recommended doses and may change for different countries.

In addition to these quantity-based n-FUs, functional units can also be defined on a nutrient basis. This approach accounts for the *nutritional content* of food products, focusing on specific macronutrients (e.g., grams of protein) or micronutrients (e.g., milligrams of essential vitamins such as vitamin C or B12). Alternatively, *calories* (kcal) can serve when the primary concern is energy intake. Protein content is the widest used n-FU, even if some worries about its effectiveness are acknowledged [20], [21], [24]. Some authors suggest using *quality adjusted protein*, to take into consideration the quality of the proteins [20], [21], [24].

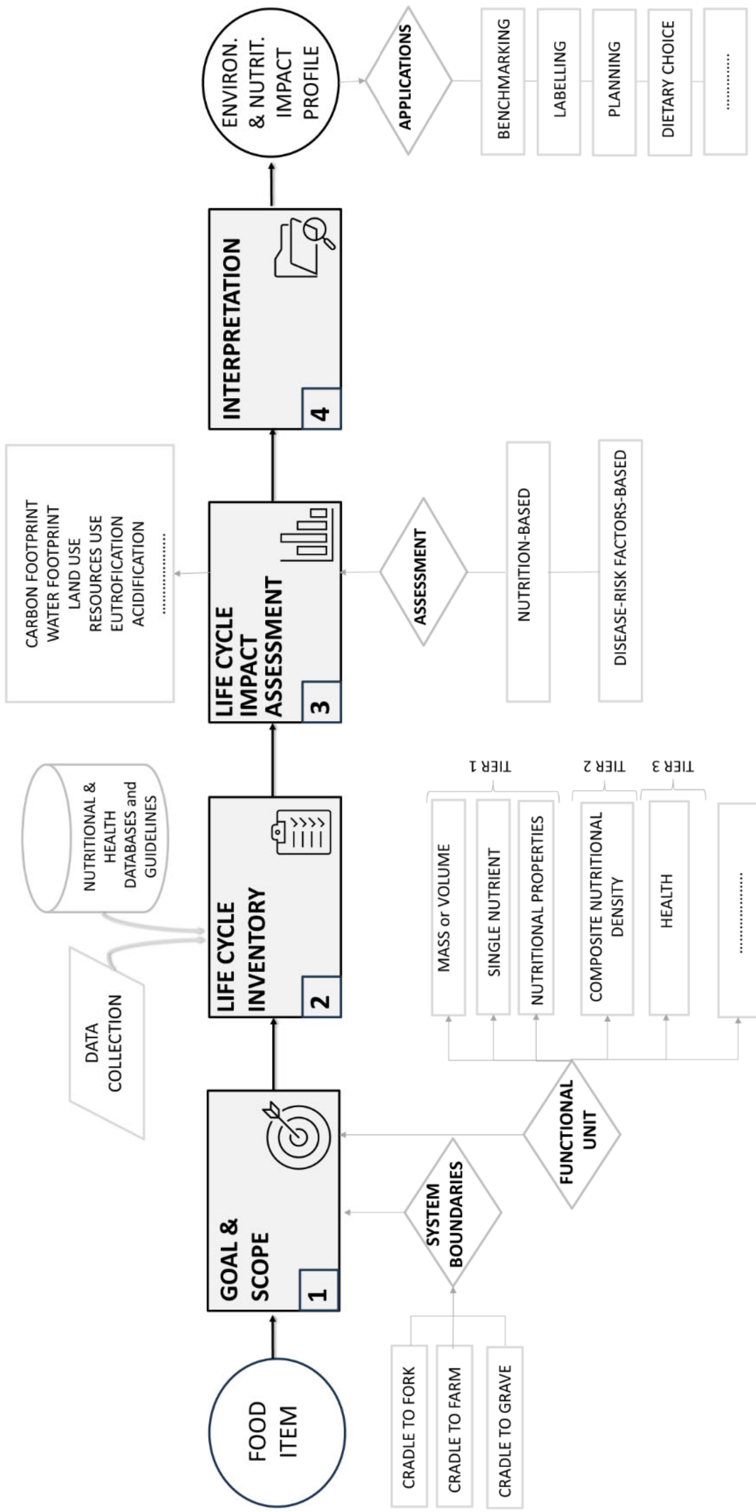

Figure 1: Workflow for n-LCA. *(Source: Adapted from McAuliffe et al. [24].)*

n-FU can be designed to capture a broader spectrum of a food product's attributes by incorporating a combined scoring system that weighs both beneficial and detrimental nutrients. It can be designed also to reflect more than a single aspect of a food product through combined score weighting measures of qualifying and/or disqualifying nutrients. One notable example of a multi score FU, among others, is the well-established *nutrient rich food (NRF) index* [29], specifically the NRF9.3 score and its variants. This scoring system evaluates the nutritional content of food products on the basis of the content of nine nutrients to encourage – protein, fibre, vitamins (A, C, D), minerals (calcium, iron, potassium, and magnesium) – while simultaneously accounting for three nutrients to limit – saturated fatty acid (SFA), added sugar, and sodium. The NRF9.3 score provides a comprehensive measure of a food product's overall nutritional quality, balancing the benefits of essential nutrients with the potential risks associated with overconsumption of certain detrimental components. By combining multiple nutritional factors into a single score, the NRF9.3 and similar indices can serve as effective tools for comparing the healthfulness of different foods, thereby helping to identify options that are both environmentally sustainable and nutritionally beneficial. On the other side, this n-FU is a more complex and harder to understand than others.

Another interesting proposal for a suitable n-FU is a product-group-specific nutrient index especially for protein-rich foods [19].

Alternative n-FUs are oriented towards the consequences of nutrition on human health (for example using disability-adjusted life years (DALY)). Despite its great potential, it is particularly complex, too aggregated and therefore not always easy to interpret [18].

The impacts profile generated by LCA can be categorised as (i) nutrition based (mid-point type) or (ii) disease-risk factors-based (end point type) [13], [14], [20], [24]. The first class is focused on the nutritional value of food, based on the content of individual nutrients or metric describing nutritional quality based on several nutrients. Mid-point indicators focus on the observation and quantification of changes in the natural environment caused by emissions or resource use due to the production of that product. These indicators are often easier to calculate and understand as they are closer to the source of the impact and less affected by uncertainties and assumptions. However, they may not capture the full consequences of environmental changes for human well-being or ecosystem services and may not reflect the relative importance or severity of different impact categories. The second group analysed the dietary health effects, for example by using health metrics to estimate the dietary impact on a specific health outcome. End-point indicators, on the other hand, are oriented towards the final damage or benefit to human health, natural resources, or biodiversity caused by emissions or resource use. Although these indicators are often more relevant and comprehensive as they show the ultimate outcomes of environmental changes, they may be more difficult to calculate and interpret. This complexity arises because end-point indicators require more data and modelling and involve more uncertainties and value judgments.

3 RESULTS AND DISCUSSION

3.1 SWOT analysis

The n-LCA is becoming a powerful impact assessment tool capable of addressing the complexities inherent in evaluating the sustainability of food systems and offering new and important perspectives. Through the framework of SWOT analysis, the current state of the methodology is analysed, and the relative results are presented in Fig. 2. By systematically

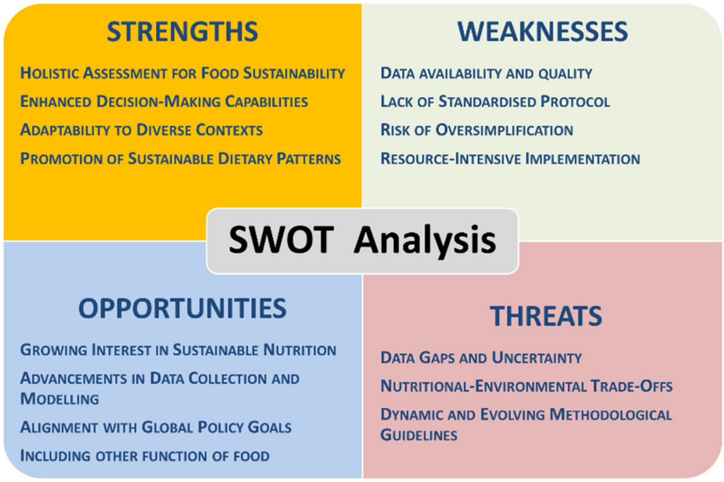

Figure 2: The SWOT analysis that summarises the main strengths and weaknesses, with opportunities and threats for n-LCA.

evaluating strengths, weaknesses, opportunities, and threats, the SWOT analysis provides a comprehensive understanding of how the methodology can be optimised for more effective application in various contexts.

Despite its recent introduction, the 'dual lens' approach of the n-LCA – considering not only the environmental impact but also the contribution to human nutrition and well-being – is the highlight of this method. This results in a more comprehensive and holistic sustainability assessment of food systems. The framework is adaptable and flexible, allowing it to be customised for specific food products, dietary patterns, or regional contexts, making it more relevant and applicable. This contributes to promoting sustainable dietary patterns. Overall, n-LCA facilitates informed decision-making for policymakers, producers, and consumers by identifying management strategies that optimise both environmental and nutritional outcomes, thus preventing the transfer of burdens among them.

On the other hand, there are several weaknesses that need to be addressed in order to make the n-LCA more robust and affordable. Reliability depends on the availability and accuracy of data: an extensive and detailed nutritional and environmental dataset is required. While this aspect is recommended, its high complexity can often be a deterrent to its use. The absence of a universally accepted standardised protocol for n-LCA can lead to variability in outcomes, reducing the comparability and reliability of results. Additionally, integrating complex nutritional and environmental information into a single assessment may oversimplify things, and caution must be exercised. It is recognised that LCA-based frameworks are all resource-intensive and require significant investments in time, financial resources, and expertise, which may limit their widespread adoption. Certainly, n-LCA presents important challenges. It increases and stimulates global interest in sustainable diets and can support international policy initiatives aimed at improving nutrition and reducing environmental impacts, aligning with the Sustainable Development Goals (SDGs). Furthermore, advancements in data collection, processing, and modelling can improve the precision and efficiency of n-LCA, making it more accessible and reliable. Gaps or uncertainties in data can compromise the robustness of the analysis. Similarly, the perceived complexity, cost, and resource requirements may lead to resistance from stakeholders, hindering widespread implementation of n-LCA. n-LCA could reveal trade-offs between nutritional quality and environmental impact, posing challenges in balancing these aspects and making difficult decision-making scenarios. It should not be underestimated that the continuous evolution of dietary and environmental guidelines requires regular updates to n-LCA methodologies, which may introduce challenges in maintaining consistency and comparability over time.

The findings of this analysis underscore that n-LCA emerges as one of the most compelling indicators and metrics available in literature for evaluating sustainability within the agro-food sector. Given its potential to advance our understanding of sustainable food systems, further exploration and refinement of the n-LCA methodology are highly warranted. Enhancing the accuracy, relevance, and applicability of n-LCA will be crucial for developing a more effective tool and committed to fostering sustainable agricultural practices and improving public health outcomes.

3.2 The selection of n-FU: the case study of oils and fats food groups

The selection of an appropriate n-FU is a pivotal aspect of the n-LCA, as it significantly affects the analysis's outcomes. As highlighted in the previous paragraph, the complexity of this decision is amplified by the complexity inherent in the research question and the desired analytical outputs. Currently, there is no universally accepted standard for determining the most suitable n-FU across all food categories. Recognising that food items can generally be grouped into relatively homogeneous groups based on the key nutrients they provide, a feasible approach could involve proposing food group-specific n-FUs accordingly also to other papers [19]. The underlying rationale is to underscore the nutritional value inherent in each food group, reflecting the primary reasons for their consumption, without accounting for any potential negative impacts. Moreover, this method emphasises the substitutability of products within the same category. By aligning the n-FU with the specific characteristics and functions of each food group, this method enhances the relevance and precision of the n-LCA, ultimately contributing to more informed decisions in food production and consumption.

To illustrate the significant role of selection of the FU and make it more explicit, the 'oils and fats' food group was considered. This category plays a crucial role in human nutrition and includes both plant-based oils and animal-derived fats. These dietary fats provide essential calories for energy and facilitate the absorption of fat-soluble vitamins (i.e., E, A, and D). Beyond their nutritional value, dietary fats serve important physiological functions, such as protecting vital organs, regulating body temperature, and contributing to overall health. The fundamental components of oils and fats are fatty acids, which are categorised into two primary types: unsaturated and saturated. Unsaturated fatty acids, which are liquid at room temperature, include both monounsaturated and polyunsaturated fats. In contrast, saturated fatty acids remain solid at room temperature. All dietary fats consist of a combination of these fatty acids in varying proportions.

Both oils and butter have distinctive roles in the diet, offering unique benefits and often being used interchangeably depending on culinary needs and health considerations. Oils, predominantly composed of unsaturated fatty acids, are frequently lauded for their heart-health benefits, as they can help lower levels of LDL (bad) cholesterol. Additionally, many oils, particularly those derived from seeds and nuts, are rich sources of vitamin E, an antioxidant that protects cells from oxidative stress. Conversely, butter, which is high in saturated fats, has been associated with elevated cholesterol levels and an increased risk of heart disease when consumed in large quantities. However, butter also provides fat-soluble vitamins such as A, D, E, and K, contributing to its nutritional value.

Once analysed the most relevant nutritional properties of this food group, three single score n-FU (tier 1) have been proposed for impact assessment: (i) energy intake (calories); (ii) the content of MUFA (monounsaturated fatty acid); (iii) the content of vitamin E. Then, a set of oils, seeds oils, and fats from plant as well as some commonly used butters have been selected and relative information collected. The nutritional composition information was obtained from the Ciqual table, one of the most comprehensive food composition databases in Europe [30]. Environmental data, covering the entire lifecycle 'from cradle to table', was sourced from the Agribalyse database [31], which provides extensive LCA data for a wide range of agricultural products and food items. Results for each type of fat are presented based on the selected n-FUs and are assessed across two impact categories: contribution to climate change and water use (see Table 1). Within each column, the ranking is indicated using a colour spectrum that ranges from green (lowest impact) to red (highest impact), reflecting the median value.

When using a mass-based n-FU, oils and butter exhibit different environmental impacts with their footprints varying widely depending on the type of product and specific agricultural and processing practices. Generally, butter has a higher carbon footprint due to livestock-related emissions but is relatively low in water intensity. In contrast, while the water footprint of certain oils can be significantly high depending on the crop and region, the carbon footprint of oils is generally lower than that of butter. This underscores a key point: assessing sustainability requires considering multiple impact categories, as a single category alone is not sufficient.

Examining the carbon footprint profile, which measures the contribution to climate change for each nutritional unit, the difference in impact between oils and butters is quite evident. For each n-FU, butters consistently have higher impact indexes, marked in red, indicating significant environmental concerns per nutritional unit. In contrast, oils exhibit more variability in their impact rankings, but generally have lower values.

Energy intake, as an n-FU, shows a ranking closely aligned with that of mass, providing no additional insights since the calorie counts of the products are similar. On the other hand, the other two n-FUs – MUFA and vitamin E – reveal substantial variations in their rankings, offering more nuanced information about environmental impact.

The water footprint profile, which measures the water use required to produce one unit of each nutrient, generally reduces the significance of the impact of butters (i.e., there are fewer red boxes) and highlights the water-intensive nature of certain oils, such as avocado and cottonseed oil. Again, the mass- and energy intake-based n-FUs provide similar perspectives, while MUFA and vitamin E offer a more integrated view of the overall impact.

The overview of each profile provides insights into specific impact categories, but interpreting all selected n-FUs together can be challenging. This is a key limitation of Tier 1 n-FUs, and for this reason integrating nutrient indices as n-FUs should be explored.

4 CONCLUSIONS

The n-LCA approach represents a significant advancement in the field of life cycle assessment, offering a more comprehensive framework for evaluating the sustainability of food systems. While traditional LCA has been invaluable in assessing and documenting the environmental impacts of products and processes, its exclusive focus on ecological factors highlights the need for evolving methodologies that incorporate broader aspects of sustainability, including nutrition and human health. By integrating nutritional

Table 1: Carbon footprint and water footprint profiles of 'oils and fat' food group across a selection of three n-FUs based on single nutrients (tier 1).

	Carbon footprint (kg CO_2/FU)					Water footprint (m^3/FU)			
	1 kg	**100 kcal**	**1 g MUFA**	**1 mg vit E**		**1 kg**	**100 kcal**	**1 g MUFA**	**1 mg vit E**
Avocado oil	4.88E+00	5.42E-02	7.48E-03	1.08E-02		1.07E+02	1.19E+00	1.64E-01	2.36E-01
Cottonseed oil	2.48E+00	2.76E-02	1.39E-02	7.03E-03		5.22E+01	5.80E-01	2.93E-01	1.48E-01
Frying oil	2.52E+00	2.80E-02	6.38E-03	4.77E-03		1.15E+00	1.28E-02	2.91E-03	2.18E-03
Hazelnut oil	8.18E+00	9.09E-02	1.08E-02	2.86E-02		2.50E+01	2.78E-01	3.32E-02	8.74E-02
Linseed oil	3.54E+00	3.93E-02	1.83E-02	3.94E-02		2.26E+00	2.51E-02	1.17E-02	2.51E-02
Maize/corn oil	3.54E+00	3.93E-02	1.29E-02	2.68E-02		1.05E+01	1.17E-01	3.82E-02	7.95E-02
Olive oil, extra virgin	9.83E-01	1.09E-02	1.34E-03	4.41E-03		2.22E+01	2.47E-01	3.04E-02	9.96E-02
Palm oil	5.55E+00	6.17E-02	1.50E-02	3.49E-02		1.82E+00	2.02E-02	4.92E-03	1.14E-02
Palm oil, refined	6.04E+00	6.71E-02	1.63E-02	3.80E-02		1.89E+00	2.10E-02	5.11E-03	1.19E-02
Peanut oil	4.24E+00	4.71E-02	6.60E-03	2.99E-02		2.45E+01	2.72E-01	3.82E-02	1.73E-01
Rapeseed oil	2.28E+00	2.53E-02	3.82E-03	8.23E-03		6.77E-01	7.52E-03	1.13E-03	2.44E-03
Sesame oil	2.28E+00	2.53E-02	5.67E-03	2.07E-01		6.77E-01	7.52E-03	1.68E-03	6.15E-02
Soy oil	2.84E+00	3.16E-02	1.29E-02	4.66E-02		3.56E-01	3.96E-03	1.61E-03	5.84E-03
Sunflower oil	2.58E+00	2.87E-02	9.35E-03	4.50E-03		1.27E+00	1.41E-02	4.60E-03	2.22E-03
Butter, 39–41% fat, light, unsalted	6.18E+00	1.58E+01	5.78E-02	5.07E-01		1.99E+00	5.09E-02	1.86E-02	1.63E-01
Butter, 60–62% fat, light, lightly salted	7.11E+00	1.28E+01	4.47E-02	4.50E-01		2.29E+00	4.13E-02	1.44E-02	1.45E-01
Butter, 60–62% fat, light, unsalted	7.15E+00	1.30E+01	5.11E-02	5.18E-01		2.30E+00	4.18E-02	1.64E-02	1.67E-01
Butter, 80% fat, lightly salted	7.73E+00	1.05E+01	3.65E-02	3.66E-01		2.48E+00	3.36E-02	1.17E-02	1.18E-01
Butter, 80% fat, salted	7.73E+00	1.06E+01	3.92E-02	4.37E-01		2.48E+00	3.39E-02	1.26E-02	1.40E-01
Butter, 82% fat, unsalted	7.79E+00	1.03E+01	4.04E-02	8.66E-02		2.50E+00	3.32E-02	1.30E-02	2.78E-02
Median value	**4.56E+00**	**5.06E-02**	**1.34E-02**	**3.64E-02**		**2.30E+00**	**3.37E-02**	**1.28E-02**	**8.35E-02**

Note: The cells of each column are coloured based on ranking from lowest (green) to highest (red), according to the median value.

considerations, n-LCA moves beyond the conventional scope of LCA, addressing the complex interplay between food production and consumption, and long-term sustainability. This approach shifts the focus toward minimising trade-offs between nourishing populations and safeguarding the environment.

This paper presents a SWOT analysis that reviews the current strengths and weaknesses of the emerging n-LCA approach, underscoring its substantial potential while acknowledging the areas that require further development. One of the most significant challenges is the standardisation of the methodology, particularly in the selection of one or more appropriate n-FUs. Standardisation is crucial to ensuring consistency and comparability across studies, which is vital for the widespread adoption of n-LCA.

By examining a specific food group, this work highlights the benefits of analysing food groups rather than individual food items when assessing and comparing various impacts.

Further research and interdisciplinary collaboration are essential to refine n-LCA techniques and enhance their applicability in diverse contexts. Such efforts will be crucial for developing robust, nuanced tools that can accurately assess the sustainability of food systems, ultimately contributing to more sustainable agricultural practices and improved public health outcomes.

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