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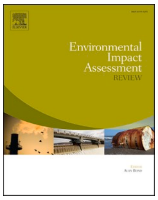

Analyzing the suitability of LCIA methods to foster the most beneficial food loss and waste prevention action in terms of environmental sustainability

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ABSTRACT

The food value chain is responsible for significant environmental and resource pressures. 14% of the total food produced in the EU is lost or wasted along the supply chain (FAO, 2019) and 19% is disposed of when reaching the consumption stage (UNEP, 2024). Therefore, to tackle the problem of food loss and waste (FLW), it is crucial to make the agri-food system sustainable. Adopting a life cycle approach to measure and assess the impacts created by FLW prevention actions is key to achieving this transition. This paper provides a detailed mapping study of EU projects that previously dealt with the issue of FLW prevention and compiles the LCIA methods that were used to conduct their environmental assessments. Two essential requirements are set to evaluate the suitability of the identified LCIA methods to detect the most beneficial FLW prevention and reduction (FLWPR) action in terms of environmental sustainability. Results show that the Environmental Footprint v3.0 method (EF v3.0) is the LCIA method that better meets these requirements. To shed light on its suitability, this paper uses the EF v3.0 method to make a comparative LCA of two specific hypothetical FLWPR actions concerning the fresh tomato value chain. Moreover, this study highlights the strengths of this LCIA method and explores pathways to overcome possible shortcomings. The outputs of this study represent an academic breakthrough in the field of FLWPR by addressing the requirements for guiding the selection of a method that enhances comparability between FLWPR actions and provides science-based tools that can help decision-makers follow a path to a more sustainable agri-food system.

1. Introduction

In 2020, the European Commission unveiled a new Circular Economy Action Plan (CEAP) designed to promote a more competitive and cleaner Europe (European Commission, 2020a) and to accelerate the transformational change requested by the European Green Deal strategy (European Commission, 2019). This plan outlines a forward-looking pathway for reaching a more competitive and cleaner Europe in collaboration with consumers, economic actors, civil society organizations, and citizens in response to the Sustainable Development Goals (United Nations, 2015). Circular Economy (CE) is a vital element in reducing the adverse impacts of resource extraction and use on the environment, as well as in contributing to restoring natural capital in Europe (Gladek, 2017).

Food, water, and nutrients are key product value chains identified in the CEAP. The food value chain is accountable for considerable environmental and resource pressures. 14% of the total food produced in the EU, excluding retail, is lost or wasted (Food and Agriculture Organization of the United Nations (FAO, 2019)) and 19% of food that reaches the consumption stage is wasted by retailers, food services, and households (UNEP, 2024). The European Commission, as part of the Farm-to-Fork Strategy (European Commission, 2020b), is committed to achieving the SDG Target 12.3 of halving per capita food waste at a retail and consumer level by 2030. To accelerate the progress towards this target, the Commission also proposes a set of legally binding food waste reduction targets for Member States, which include an FLW reduction of 10% in processing and manufacturing; and of 30% per capita, jointly at retail and consumption levels by 2030 (European Commission, 2024). However, the world is falling short in its efforts to achieve these figures, and data are still scarce. Therefore, it is essential to implement data-driven policies as well as to invest in technologies, infrastructure, education, and monitoring to tackle FLW and support a shift towards

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sustainable practices and disconnect economic growth from resource utilization (United Nations, 2023).

The enormous impacts of the misuse of food highlight the problem of FLW, which has become a major issue in recent decades (Niu et al., 2022). For this reason, many studies have identified its potential causes and solutions. ToNoWaste (2023b) offers the results from an open discussion, which took place in 2022, between the different stakeholders and experts of the project. The results obtained from these discussions reveal the complexity of the FLW problem and the design and implementation of potential prevention and reduction measures. During the workshops, misinformation, and a lack of knowledge among producers, manufacturers, and consumers concerning the environmental, social, and economic impacts of FLW were identified as considerable threats.

Thus, to make the agri-food system sustainable, it is crucial to comprehend and measure its sustainability impacts and influences on the ecological boundaries. This can be achieved by enhancing the knowledge base through cross-sectoral assessments, modeling, and scenarios (European Commission, 2018). In literature, sustainability is generally defined against a complex and broad background that hinders its operability in specific contexts. Muñoz-Torres et al. (2018) detected this obstacle and highlighted four common and basic conceptual principles of sustainability based on a strong sustainability approach. These principles include the three dimensions of sustainability (economic, environmental, and social) and the proper balance between them. In addition, they include the intergenerational perspective, the multi-stakeholder approach, and the life cycle thinking approach. This latter approach requires impact management of upstream and downstream activities from a system perspective. The life thinking approach also has a strategic position in the European policymaking process (Del Borghi et al., 2020) and offers a golden opportunity to smooth the transition to a Circular Economy (Ruiz-Salmón et al., 2020).

As an example of this policy commitment, the European Commission is currently running several research projects under the Horizon Europe Work Programme 2021–2022 "9. Food, Bioeconomy, Natural Resources, Agriculture and Environment". This Programme seeks to develop a comprehensive, evidence-based analysis of food losses and waste prevention and reduction (FLWPR) actions to inform decision-making actors who are willing to implement them. The performance of impact assessment and cost-benefit analysis of existing FLWPR actions, as well as their impacts on economic, environmental, and social dimensions, is used as a tool for this development (European Commission, 2020c). Moreover, topics explored in the 2023–2024 version of this Work Programme (European Commission, 2022) stress the strategic importance for the European Union of transitioning to more resilient and environmentally, socially, and economically sustainable food systems through the prevention and reduction of food waste in a sustainable manner.

A clear and common definition of FLW is essential to analyze any economic, social, or environmental impact along the whole supply chain. Different definitions are offered (Amicarelli et al., 2021b; Karin Östergren et al., 2014; Thanomnim et al., 2022; Tóffano Pereira et al., 2022) and the present study adopts the one given by the Food and Agriculture Organization of the United Nations. It states that "*food loss refers to the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers*" while "*food waste refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers*." (Food and Agriculture Organization of the United Nations (FAO, 2019)).

The lack of standardization is one of the main weaknesses of sustainability accounting and assessment (Nita et al., 2022). Life Cycle Assessment (LCA) is a globally acknowledged technique to systematically evaluate the environmental performance of different processes, activities, and products (Mehrpouya et al., 2019) and appears to be the general approach to assess the environmental impacts of food systems and FLW (Corrado et al., 2017; Winans et al., 2020). The development of the ISO 14040 series standards (2006a) represented an important milestone in consolidating procedures and methods of LCA (Finkbeiner et al., 2006).This standard describes four phases of an LCA implementation: (i) goal and scope definition; (ii) life cycle inventory analysis; (iii) life cycle impact assessment; and (iv) life cycle interpretation. The Life Cycle Impact Assessment (LCIA) stage evaluates the potential environmental impacts by converting the Life Cycle Inventory (LCI) data into specific impact indicators to better understand their environmental significance. However, this standard highlights the lack of generally accepted methods to associate the environmental inventory data consistently and accurately with the potential environmental impacts. It is crucial to choose a characterization, normalization, weighting and aggregation approach that is consistent with the decision maker's information needs (Rowley et al., 2012). Furthermore, the huge variety of framework conditions and the scarcity of studies adopting consistent assumptions to perform LCA hinders and compromises the comparison of results (Boschiero et al., 2023; Kohlheb et al., 2021). This wide diversity has led to the use of different functional units, length of life cycles, characterization models with their associated impact categories, databases, and general assumptions. The huge space for defining these LCA framework conditions can increase the risk of not properly achieving the objectives of the assessment (Amicarelli et al., 2021a).

To make better decisions regarding FLWPR, it is essential to advance in the development, standardization, and consistency of sustainability accounting methodologies to assess FLWPR actions. Thus, the main objective of this study is to select the LCIA method that can best guide the decision on the most beneficial FLWPR action by assessing the environmental implications of such actions along the supply chain. It focuses on the environmental dimension of sustainability due to the severity and relevance of environmental risks in the current and future world (World Economic Forum, Marsh McLennan, and Zurich Insurance Group, 2023). To achieve this goal, the present research is structured as follows.

The first part analyses how previous European projects assessed the environmental dimension in the field of FLWPR actions to identify previous research, their strengths, weaknesses, and limitations. Previous European projects offer high-quality research problem-oriented results due to their access to advanced resources, multidisciplinary collaboration, and significant impact at the industry and society level. This review is directly aimed at detecting the LCIA methods used in their assessment processes. To conduct this review, a systematic mapping study of European Research Projects focused on FLWPR strategies is carried out. This study adjusts the research method proposed by García-Holgado et al. (2019) for mapping studies. Two European project databases are used: CORDIS and BBU JU; and European research projects from 2013 to 2023 are analyzed. Once LCIA methods are identified, two main requirements that methods should meet to optimally perform a comprehensive comparative assessment of the environmental performance of FLWPR actions to achieve the goals of this research are proposed. Finally, a theoretical analysis of the LCIA methods is drawn attending to their specific properties. These two requirements, together with the analysis of the properties of each method, lay down the criteria for selecting the most suitable LCIA method for promoting the most environmentally beneficial FLWPR action.

The second part consists of a comparative assessment of two specific FLWPR actions in hypothetical simulated scenarios by using the selected LCIA method (EF v3.0) aiming to evidence its suitability for this research. The tomato supply chain is chosen to conduct this demonstrative assessment since this food product is one of the most highly consumed fruit or vegetable crops worldwide for its nutritional benefits (Karthick et al., 2023) and has a large environmental impact (Martella et al., 2023). In this context, both actions focus on the use of a retailer's fresh tomato which due to, for instance, inadequate demand forecasting (Magalhães et al., 2022) can potentially become waste if no FLWPR action is taken, as raw material to elaborate some new processed food products ready to be sold at the retailer, thus avoiding the wastage of fresh tomato. The processed products are dehydrated tomato soup (action 1 in scenario 1) and tomato juice (action 2 in scenario 2); which are both produced from fresh tomato. Both actions related to food transformation can be included in the category of "solutions based on technological aspects" described in this paper. This category is highly relevant since the United Nations (2023) pointed out that one of the main requirements to tackle FLW is to invest in new technologies. Furthermore, a scenario where no action is taken (scenario 0) is also introduced in the assessment to reflect how the selected LCIA method can, as well, be used to assess the environmental implications of wasting food. The empirical analysis of these three scenarios aims to shed light on how the process of assessing the environmental impacts of FLWPR actions, using the selected LCIA method can, in turn, facilitate the process of comparing and continuously improving the assessed FLWPR actions, identifying hot spots, planning actions, evaluating corrective solutions and suggesting improvements.

Many authors previously focused their studies on comparing different LCIA methods. However, most of these studies made comparisons based on the environmental impact results of specific products to evidence that different methods give different impact values for the same product (Borghesi et al., 2022; Bueno et al., 2016; Owsianiak et al., 2014; Rashid and Liu, 2021); or only focused on specific kinds of impacts, such as biodiversity impacts and their associated impact categories (Sanyé-Mengual et al., 2023). Other authors drew comparisons between midpoint and endpoint approaches for a specific field (Dong et al., 2016) or performed an overview and systematic comparison of a selection of the most used LCIA methods in general terms, not linking them with a specific field (Hauschild et al., 2017).

This study represents a significant leap forward in the realm of research on assessing the environmental implications of FLWPR actions along the supply chain and on selecting the most sustainable one according to this assessment. Firstly, it greatly contributes to making a broader comparison of LCIA methods previously used in EU research and innovation projects and linking these methods with the specific area of FLWPR. Rather than starting by exploring the environmental impacts of a specific product or impact category, as in previous studies, this research is pioneering in laying down a set of key requirements to ensure that the LCIA assesses the environmental implications of FLWPR actions in the most optimal way to achieve the goal of contributing to the provision of tools to guide the selection of the most sustainable one. Then, once the most suitable LCIA method to achieve this goal is selected (EF v3.0), the empirical LCA is intended to further demonstrate how the method can be used effectively for establishing the comparison between FLWPR actions to detect the most environmentally sustainable one. This research focuses on the specific properties of the method, rather than on the numerical impact results obtained. Finally, by addressing essential requirements for guiding the selection of a method that enhances comparability between FLWPR actions, our study not only advances the existing literature but also contributes significantly to accelerating continuous improvement processes of this kind of action providing tools to detect hotspots along the supply chain.

This document is structured as follows. Section 2 presents a state-of-the-art review of the environmental assessment of food loss and waste prevention and reduction actions. This section also shows a mapping study of previous EU research and innovation projects in the field of FLWPR. Section 3 provides a comparative analysis of LCIA methods identified in the previous review, and accounts for the selection of the most suitable method. Section 4 looks at the empirical application of the selected LCIA method through the LCIA of two FLWPR actions and a baseline scenario. Finally, Section 5 presents the conclusions of the study and identifies limitations and areas for further research.

2. A state-of-the-art review of the environmental assessment of FLWPR actions

Determining whether business firms can contribute to sustainable development involves the practices of both sustainability accounting and sustainability management (Burritt and Schaltegger, 2010). However, current corporate sustainability accounting exposes limitations on the inclusion of life cycle thinking, commensurability and offsetting effects and the environmental, social, and economic dimensions from a balanced perspective (Muñoz-Torres et al., 2018). In the same vein, Gallo et al. (2023) proposed a model to correlate circularity with environmental impacts based on the Material Circularity Indicator tool (MCI) and Life Cycle Assessment (LCA). The model was tested on five case studies, and this comparative analysis showed that circularity does not always necessarily lead to a reduction of environmental impacts due to its dependency on the product and type of impact.

Regarding the agri-food sector, recent articles revealed different limitations on its current sustainability assessment. On the one hand, most of the existing assessments are static without representing system feedback (Hadjikakou et al., 2019). Another limitation lies in the multidimensionality of the sustainability assessment of global food systems (Hoehn et al., 2021; Muñoz Torres et al., 2022), the lack of homogeneity among key FLW factors (Corrado et al., 2017), and the need to include aspects like health, resilience, sociocultural well-being and food affordability and availability (Chaudhary et al., 2018). Furthermore, Fernandez et al. (2021) detected that the use of new technologies in the agro-industrial sector offers huge sustainability advantages, although a lack of awareness of the benefits of their implementation is one of the main barriers to its adoption.

In terms of the sustainability assessment of FLWPR actions, the Joint Research Centre published in 2019 a technical report that provided an assessment framework to evaluate the performance of FLWPR actions (Joint Research Centre (JRC) (European Commission), 2019). This framework particularly focuses on cost and environmental impact variables and includes a 'calculator' designed using life cycle thinking and the Environmental Footprint v2.0 LCIA method as a reference, as a technical tool to foster practitioners to quantify the economic benefits and environmental savings of FWPR actions (De Laurentiis et al., 2020). That same year, the Food and Agriculture Organization of the United Nations published a report to acknowledge the need to reduce food loss and waste and to provide guidance on how to target interventions and policies depending on the information available and the policymakers' objectives. This report (Food and Agriculture Organization of the United Nations (FAO, 2019)) also states that fully understanding the problem of food loss and waste reduction might help to increase the efficiency of the food system, improve nutrition and food security, and promote environmental sustainability.

Furthermore, several authors studied the use of LCA in the field of FLWPR. Winans et al. (2020) reviewed 222 studies that include FLW in LCA and observed that most of the research is focused on waste or waste treatment while only two of those studies dealt with loss prevention. These authors also evaluated the environmental impacts of an on-farm food loss prevention action using LCA models and concluded that the inclusion of life cycle thinking facilitates the identification of opportunities and challenges to guide interventions that reduce food losses and their associated environmental impacts.

Moreover, the EU is allocating funds to research and innovation projects to smooth the shift to food systems that are more resilient and environmentally, economically, and socially sustainable through the prevention and reduction of food waste. One of the objectives of this paper is to perform an in-depth analysis of these projects and examine the environmental assessment of FLWPR actions. The next sections seek to describe the process for carrying out this analysis.

2.1. A review of previous EU Research and innovation projects

The first objective of this paper is to explore how previous European projects assessed the environmental dimension of FLWPR actions. The authors paid special attention to the use of LCIA methods. This section provides a detailed description of the mapping strategy, project identification process, and information gathering.

2.1.1. A systematic mapping strategy

The mapping study of EU-funded research projects on FLWPR was performed by using a four-staged framework. The selection criteria established by García-Holgado et al. (2019) for mapping studies of EU-funded projects were adapted to the area of FLWPR accounting methodologies. The analysis process is structured into the following four phases:

1. *Key mapping questions*

Three mapping questions on the specific objectives of this paper were asked. These questions (see Fig. 1) aim to gather information on FLWPR actions along the supply chain including the methodological approaches to assess their performance.

2. *Search Strategy*

To define the search period, the European project FUSIONS (2012–2016) served as a point of reference due to its pioneering contribution to the analysis of FLWPR strategies. For this paper, articles were searched from 2013 until 2023. In this manner, all projects, before and after FUSIONS were taken into consideration.

Community Research and Development Information Service (CORDIS) and Bio-based Industries Joint Undertaking partnership (BBU JU) databases were used in this study for extracting information. CORDIS is the main international source of results from EU-supported projects while the BBU JU database is a specific European database that focuses on bioeconomy.

There is a search section on the CORDIS database where ̇food loss” or “food waste” command was used, which provided 333 research outputs. The BBU JU database lacks the possibility of adding filtering criteria; therefore, all the projects on this database (124) were initially considered. All the projects available on the BBU JU database can also be found on CORDIS; however, some of them are out of scope when searching “food loss” or “food waste” in the CORDIS search tool. Therefore, the BBI JU database contains key FLWPR projects on bioeconomy. Searches on both databases were done in December 2022.

3. *Inclusion criteria*

Six inclusion criteria were defined to narrow down results due to the general nature of the first search (see Fig. 1). Specifically, three of the generic criteria established in the reference framework were applied according to their authors (IC2, IC4, and IC6). The three remaining criteria were slightly adapted to meet the requirements of the present study (IC1, IC3, and IC5).

4. *Quality criteria*

After the application of the six inclusion criteria, projects that provide scarce information and, therefore, do not attain the objective of the study were discarded. However, the amount and quality of the information available regarding the preselected projects may be insufficient to answer the questions of this study. To ensure that the quantity and quality of information is enough, eight quality criteria, as Fig. 1 illustrates, were applied. As was the case with the inclusion criteria, some general questions were taken from the previous baseline framework (QQ1, QQ2, QQ3, QQ4, and QQ7), while the remaining three were adapted to the specific objectives of this study (QQ5, QQ6, and QQ8).

2.1.2. Project identification

Data extraction starts with an iterative process to identify relevant projects. This process follows the steps in the PRISMA flow diagram in Fig. 2 and is guided by the information in Fig. 1. A comprehensive step-by-step description is shown in successive organizational tables[1] on a spreadsheet. The information extracted from the selected projects is compiled in Table 1.

Upon eliminating duplicate results from both databases, 461 projects were obtained. The first step gather general information on the 461 projects. The CORDIS database offers the possibility of downloading a CSV file that contains this information. Yet, projects from the BBI JU database were manually collected.

In the second step, the inclusion criteria (IC) were applied to select projects. Projects were marked “yes” or “no” whether they met the criteria or not. In general, projects were approved for the filtering next stage if all the ICs were fulfilled. However, there are some exceptional cases in which the relevance of the project requires it to be selected, although one of the inclusion criteria was marked “no”. This is the case of four projects that were launched before January 2013 and four other projects that belong to a very general call; yet they met the rest of the criteria quite acceptably. After this step, 50 projects moved forward to the next filtering stage.

Eight quality criteria (QC) were applied to select the projects of the wide review (Fig. 2). Each project is assigned a quantitative score based on the answers to each of the quantitative criteria. In this sense, a score of 1 was assigned to each criterion that met the project requirements, a score of 0.5 was assigned to the criterion that was partially or not yet met and a score of 0 was allocated to the criterion that was not met. The project was deemed feasible if the resulting total score was at least 5.5. However, there is one project whose score fell below the threshold and it was accepted due to the relevance of the information provided.

After this last filtering stage, 21 projects were considered for the wide review (Fig. 2). The relevant information on the technical aspects associated with FLWPR actions was extracted from the project deliverables. This information was compiled, tabulated, and organized on another spreadsheet.

Finally, projects were classified based on their distinctive characteristics. A preliminary analysis was offered attending to the nature of the solutions to the problem of FLW provided by each project. The categories were based on the proposal Bocken et al. (2014) put forward, which provided solutions based on technological, social, and organizational aspects. The following sections deal with the 10 projects that fall into the technological category, which are part of the narrow review. Nevertheless, the information regarding sustainability measurement and accounting methodologies extracted from the wide review is compiled in ToNoWaste (2023a).

Several authors highlight the evidence that the development of technologies helps to minimize the inefficiencies of processes and, consequently, boost the efficiency of the agri-food supply chain (Fabi et al., 2021; Fernandez et al., 2021), which plays a fundamental role in reducing FLW (Benyam et al., 2021).

2.1.3. Information gathering

Table 1 shows relevant information from the narrow review. It also presents useful information on the LCIA methods employed by each project, on the assessment level, on the impact categories/areas of protection, on the software used for the calculations, and on the databases for obtaining the background data to develop the life cycle inventory (LCI) of the LCA. The selected projects provided FLW solutions for packaging development and the valorization process.

On the one hand, a vast variety of LCIA methods were applied and, in most cases, the approach was at a midpoint level. In addition, SimaPro, in different versions, is the software chosen by most of the projects to perform the LCA; and the Ecoinvent database is the most used source of background data. Furthermore, most of the projects only calculated the most relevant impact categories according to the product or system and

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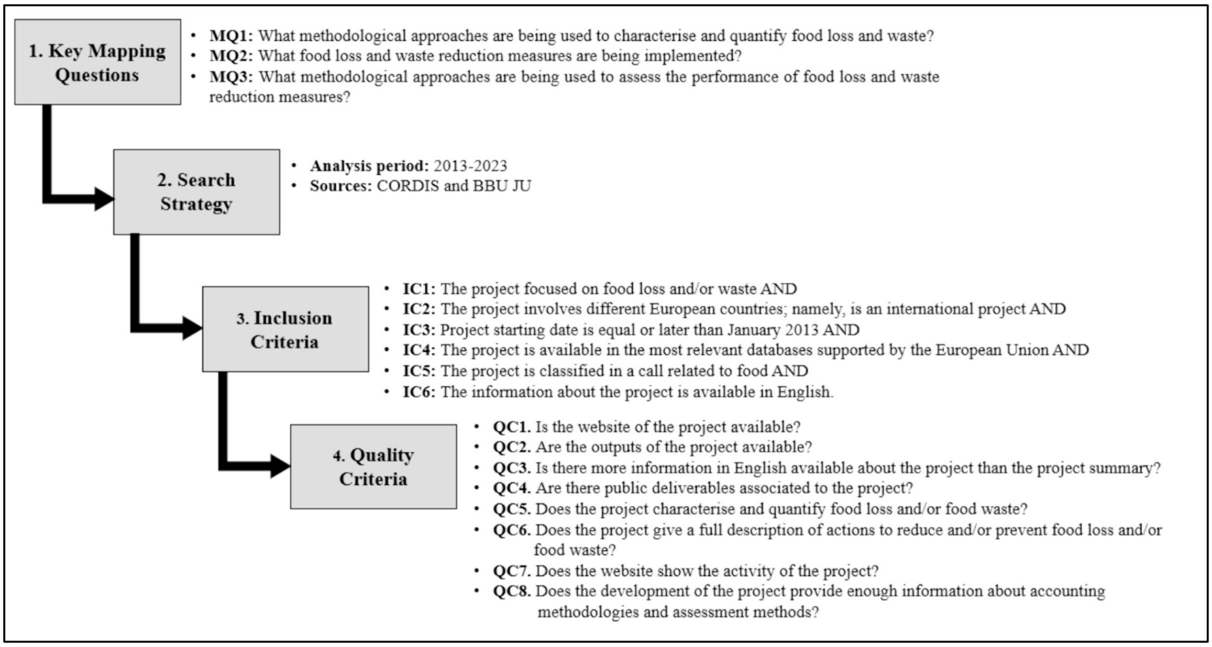
[1] Tables in this study are available at http://hdl.handle.net/10234/205262.



- **MQ1:** What methodological approaches are being used to characterise and quantify food loss and waste?
- **MQ2:** What food loss and waste reduction measures are being implemented?
- **MQ3:** What methodological approaches are being used to assess the performance of food loss and waste reduction measures?

- **Analysis period:** 2013-2023
- **Sources:** CORDIS and BBU JU

- **IC1:** The project focused on food loss and/or waste AND
- **IC2:** The project involves different European countries; namely, is an international project AND
- **IC3:** Project starting date is equal or later than January 2013 AND
- **IC4:** The project is available in the most relevant databases supported by the European Union AND
- **IC5:** The project is classified in a call related to food AND
- **IC6:** The information about the project is available in English.

- **QC1.** Is the website of the project available?
- **QC2.** Are the outputs of the project available?
- **QC3.** Is there more information in English available about the project than the project summary?
- **QC4.** Are there public deliverables associated to the project?
- **QC5.** Does the project characterise and quantify food loss and/or food waste?
- **QC6.** Does the project give a full description of actions to reduce and/or prevent food loss and/or food waste?
- **QC7.** Does the website show the activity of the project?
- **QC8.** Does the development of the project provide enough information about accounting methodologies and assessment methods?

Fig. 1. A framework for a systematic mapping study of European Research Projects on FLWPR. Source: own work.

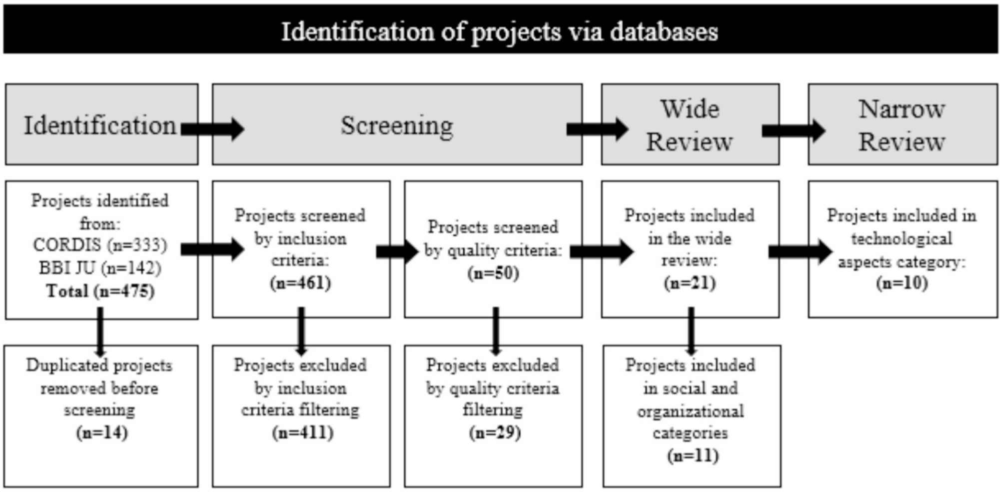


Fig. 2. Adapted PRISMA flow diagram of search methodologies for a systematic review. Source: own work.

the objectives of the assessment. In contrast, a smaller number of projects calculated all the impact categories available in the selected LCIA method.

The list of methods used for the comparative analysis in the next section includes those methods presented in Table 1, which are also available on SimaPro 9.4.0.3. These methods, which were previously used in European projects, provide a sound basis for this analysis. However, the Environmental Footprint (EF) established in 2013 adopted the format and nomenclature from ILCD (Fazio et al., 2018), therefore, this last method, although compiled in Table 1, is excluded from the comparative analysis list (section 3.2) to simplify the comparison.

3. A comparative analysis of LCIA methods

This section presents a comparative analysis of the five selected LCIA methods. The main aim is to analyze their suitability to guide the decision-making process of choosing the most sustainable FLWPR actions in terms of environmental impacts. The selected methods are ReCiPe 2008, IMPACT 2002+, ReCiPe 2016, CML 2001, and EF v3.0. This analysis was performed using scientific literature, theoretical information provided by the developers of each method, the UNE-EN ISO 14044:2006 (AENOR, 2006b) standard, and the European Commission's recommendations to measure and communicate the life cycle environmental performance (European Commission, 2013a, 2021).

3.1. *Requirements for a comparative environmental assessment of FLWPR actions*

One of the main goals of this paper is to contribute to improving the comparability of FLWPR actions and to facilitate the continuous improvement process by providing tools to identify hotspots, plan actions, assess corrective solutions, and suggest improvements. According to Muñoz-Torres et al. (2018), the fourth principle of sustainability centers on life cycle thinking; therefore, LCA is an appropriate environmental accounting tool. To make a significant contribution to LCA deployment, the present study focuses on the LCIA stage, and analyzes

Table 1
Methods of Environmental Life Cycle Impact Assessment used in previous EU projects. Source: own work.

EU Project	End date	Project aim	Environmental Life Cycle Impact Assessment Methods	Assessment level	Impact categories/Areas of protection	Software	Databases
FRESH-DEMO	28/02/2017	To reduce post-harvest waste and improve the quality of fruits and vegetables via humidification technology.	International Reference Life Cycle Data System (ILCD) 2011 Midpoint+, version 1.08	Midpoint	- Climate change - Ozone depletion - Human toxicity, non-cancer effects - Human toxicity, cancer effects - Particulate matter - Ionizing radiation HH - Photochemical ozone formation - Acidification - Terrestrial eutrophication - Freshwater eutrophication - Marine eutrophication - Freshwater ecotoxicity - Land use - Water resource depletion - Mineral, fossil & renewable resource depletion	SimaPro version 8.2.3	EU27 Input Output Database 2003
WASTE2FUELS	31/12/2018	To develop next-generation biofuel technologies to convert agro-food waste streams into high-quality biobutanol.	International Reference Life Cycle Data System (ILCD)	Midpoint	- Global Warming potential - Acidification - Freshwater eutrophication - Marine eutrophication - Terrestrial eutrophication - Ozone depletion - Photochemical ozone formation - Resource depletion water - Resource depletion, mineral, fossils, and renewables	AspenPlus. (Advanced System for Process Engineering)	Not specified
AgroCycle	31/05/2019	To improve the economic, environmental, and social sustainability of agricultural production systems through the sustainable utilization of agricultural wastes, co-products and by-products.	Product Environmental Footprint (PEF)	Midpoint	Not specified	GaBi version 8	Ecoinvent and GaBi 6
			AgroCycle protocol (AgroCycle 2017)	Midpoint	- Global warming - Acidification - Eutrophication - Water use - Land use - Mineral resource depletion - Human toxicity - Ozone layer depletion - Eco-toxicity - Photochemical smog		
			Centrum voor Milieuwetenschappen (CML) 2001	Midpoint	- Global warming (GWP100a) - Acidification - Eutrophication - Abiotic depletion - Abiotic depletion (fossil fuels)		
NanoPack	31/12/2019	To propose a solution for extending food shelf life by using antimicrobial surfaces, applied in active food packaging products.	Centrum voor Milieuwetenschappen (CML) 2000	Midpoint	- Global warming potential - Acidification - Eutrophication - Ecotoxicity - Human toxicity - Abiotic - Energy and raw materials consumption	SimaPro version 8	Ecoinvent v3.3
RES URBIS	31/12/2019	To convert several types of urban bio-waste into valuable bio-based products, in an integrated single biowaste biorefinery and by using one main technology chain.	Environmental Footprint (EF)	Midpoint	All 16 impact categories provided by this LCIA method	EASETECH (Environmental Assessment System for Environmental TECHnologies)	Ecoinvent v3.5
NoWA	31/01/2021	To contribute to a 'near zero-waste society' by promoting a circular economy in which agricultural waste, by- and	ReCiPe 2016 Hierarchist method	Midpoint	All 18 impact categories provided by this LCIA method	OpenLCA (2019 version)	Ecoinvent v3.4

(*continued on next page*)

Table 1 (*continued*)

EU Project	End date	Project aim	Environmental Life Cycle Impact Assessment Methods	Assessment level	Impact categories/Areas of protection	Software	Databases
		co-products are turned into eco-efficient bio-based products with direct benefits for the environment, economy and society.					
NEWPACK	31/08/2021	To develop and validate biodegradable plastic packaging films, able to replace conventional plastic films used for food packaging applications and aiming at prolonging the shelf lifetime of packaged food products leading to achieve the decrease of food waste and the reduction of carbon footprint of packaging film solutions.	Environmental Footprint (EF) version 3.0	Midpoint	- Climate Change (carbon footprint) - Water use (water footprint) - Land use - Resource use, energy carriers (energy footprint)	Not specified	Ecoinvent v3.4 and v3.5
			IMPACT 2002+	Endpoint	- Ecosystems Quality - Human health		
MyPack	31/10/2021	To help sustainable food packaging technologies to reach or extend their market in order to reduce waste in both food and packaging materials, and its negative impacts on the environment.	Environmental Footprint (EF) v2.0	Midpoint	- Climate Change	Not specified	Not specified
			ReCiPe 2008H/A method	Endpoint	All 3 areas of protection provided by this LCIA method		
GLOPACK	30/11/2021	To develop a biodegradable packaging, with active and/or intelligent functionalities enabling the reduction and circular management of food, including packaging and wastes.	Cumulative Exergy Extraction from the Natural Environment (CEENE)	Midpoint	- Resource footprint (MJex): abiotic renewable resources; nuclear energy; minerals (and mineral aggregates); land and biotic resources; fossil fuels; metal ores; water resources. - The cumulative degree of perfection (no units)	SimaPro version 9.1	Ecoinvent v3.6 Agrifootprint
			Environmental Footprint (EF) version 3.0	Midpoint	- Climate change (kg CO2 -eq)		
				Endpoint	- Single score of EFv3.0 (μPt)		
WASTE2FUNC	30/11/2024	To convert food and crop waste into bio-based functional molecules, lactic acid and microbial biosurfactants for the household and healthcare products industries.	Not published yet	Not published yet	Not published yet	Not published yet	Not published yet

several LCIA methods at the assessment level and whether they have the potential to fulfill the requirements for a comparative sustainability assessment (see Fig. 3). The assessment level is important since it indicates the orientation of the LCA. Optional elements shown in Fig. 3 must be considered, as they may be used depending on the objective and scope of the assessment.

First, LCA practitioners may decide whether to adopt a midpoint level, endpoint level, or both approaches in the same assessment. The damaged-oriented endpoint method shows the ultimate outcomes of environmental impacts by identifying the areas of protection, which could lead to a more comprehensive result. Some authors who focused on analyzing how functioning ecosystems support human well-being (Hardaker et al., 2022) applied the endpoint approach in their LCA studies due to its ability to characterize the severity of the actual damage that impact categories cause to ecosystems, human health, and natural resources. However, endpoint indicators also make impact identification slightly ambiguous due to their less direct link to the sources of environmental impact and value judgments. This ambiguity could result in insufficient information to detect hotspots and to choose the best alternative and could lead to major inaccuracies in the possible corrective measures. The problem-oriented midpoint approach seems more accurate in presenting a full picture of the environmental impacts associated with an activity, which may allow for a more detailed identification of hotspots. Many authors (Abu-Bakar et al., 2023; Charpentier Poncelet et al., 2022; Ferrara and De Feo, 2023; Ghisellini et al., 2023; Tushar et al., 2022) combine midpoint and endpoint approaches to further contribute to the interpretation and communication of the analysis results and, as a result, to gain the information when assessing the environmental impacts of a specific activity.

Concerning LCIA optional elements, normalized values demonstrate the relative relevance of the contribution that each impact category has on a system, comparing its value with the reference unit (European Commission, 2013b). A frequently used reference unit is the average yearly environmental burden in a country or continent, divided by the

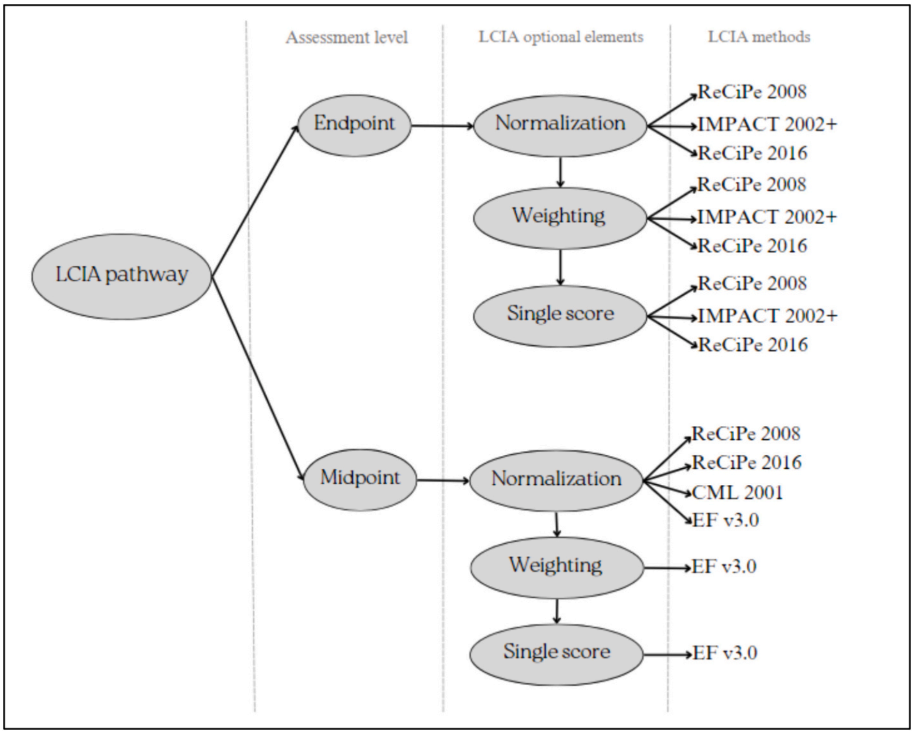


Fig. 3. LCIA pathways and calculation methods. Source: own work.

number of inhabitants, although the reference can be chosen freely (Database and Support team at PRé Sustainability, 2022). This information can be useful to identify which process, or processes of a specific activity involves the highest environmental impact focusing on specific impact categories. For instance, Kohlheb et al. (2021) applied this approach to detect the most environmentally problematic steps in the biogas upgrading process. Normalization is generally addressed in studies whose priority is the analysis of local environmental challenges (Liang et al., 2018). However, this perspective does not assess the severity of the impact itself. Thus, normalization can facilitate the communication of results since comparisons are made based on a reference situation that is external to the case studies (Pizzol et al., 2017). However, this approach is slightly limited because comparisons across impact categories cannot be done, leaving the problem of trade-offs unresolved (Pizzol et al., 2017). Moreover, in cases of complex assessments with multifaceted analysis and high dimensional data sets, aggregating values can be a tool to simplify and clarify the interpretation of results (Pollesch and Dale, 2015). Although normalized results are dimensionless, it is necessary to perform a conversion utilizing weighting factors to aggregate results across impact categories to obtain a single score (Pizzol et al., 2017).

To address the problem of trade-offs and aggregation, normalized results may be converted using selected weighting factors. With this conversion, results of the same impact category for different FLWPR actions can still be analyzed independently (e.g., climate change of action 1 compared to climate change of action 2, ozone depletion of action 1 compared to ozone depletion of action 2). Moreover, using weighting factors it is possible to go a step forward in the comparison analyzing the relative importance that one single impact category (e.g. climate change) has concerning another (e.g. ozone depletion) inside the same action (e.g. action 1). Defining the relative importance of each impact category enables the hotspots identification, detecting the most relevant one. Furthermore, this approach provides information about the relative importance of impacts, which facilitates the decision of choosing the best solution among the alternatives in situations where trade-offs hinder the selection (Pizzol et al., 2017). This characteristic can also be useful inside of a continuous improvement process highlighting the most problematic areas of a specific FLWPR action. Moreover, using a single score indicator in the comparison of different FLWPR actions ensures that all impact categories are considered in the same step, which avoids trade-offs and reduces misleading in the interpretation stage, thus improving robustness. Galafton et al. (2023) adopted this approach when attempting to assist farmers in identifying the most environmentally friendly technique for cultivating strawberries. These authors assessed the impacts of several scenarios by applying the Product Environmental Footprint (PEF) method and presented normalized, weighted, and single score results.

The main goal of the selection of an LCIA method in this study is to provide tools to promote the most beneficial FLWPR action in terms of environmental sustainability. To select the most suitable method for achieving this goal, two essential requirements are proposed (see Table 2): (i) Midpoint Approach, and (ii) Weighting Factors at Midpoint.

From the previous discussion, authors consider that the possibility of conducting the assessment from a midpoint level is an important requirement, since it helps to construct a broader picture of the environmental impacts associated with the selected FLWPR action and to identify hotspots linked to the sources of environmental impact, which may contribute to the continuous improvement process. Furthermore,

Table 2
The decision-making process to select the most suitable LCIA. Source: own work.

	Midpoint Approach	Weighting Factors at Midpoint
ReCiPe 2008	■	
IMPACT 2002+		
ReCiPe 2016	■	
CML 2001	■	
EF v3.0	■	■

weighting factors at the midpoint expose the relative importance of each impact category. This, unlike normalization, can be used to compare results across different impact categories and does not exclude comparison between the same impact categories in a similar way to normalization. Moreover, weighted results can be added to a single score and enhance the comparison of FLWPR actions considering its overall environmental impacts.

3.2. LCIA selection

Having defined the essential requirements, Fig. 3 presents the possible pathways that can be followed when performing an LCIA and the methods to calculate them. These pathways are divided into endpoint and midpoint levels and offer the possibility of normalization since it is the previous step to weighting- and weighting -as its presence is one of the requirements described. The pathways may also show the possibility of aggregating weighted results in a single score.

ReCiPe 2008, IMPACT 2002+ and ReCiPe 2016 offer tools to perform the three optional steps at an endpoint level. Turning on to a midpoint level, ReCiPe 2008, ReCiPe 2016, CML 2001 and EF v3.0 have their normalization factors that allow to perform this step at midpoint. However, only the EF v3.0 method may obtain weighted results at a midpoint level and group them in a single score.

Table 2 represents the decision-making process to select the most suitable LCIA method for the comparative sustainability assessment of FLWPR actions, which meets the essential requirements (see section 3.1) and follows the possible pathways represented in Fig. 3. In this way, the dark grey boxes show that the analyzed method offers the possibility of carrying out the assessment using each of the essential requirements. Only methods whose all boxes are in grey can be considered for our comparative study needs. In the same vein, the EF v3.0 method is the only one that satisfies this criterion.

4. An empirical application of the selected LCIA method

To pursue the research objectives and assess the selected LCIA method for making decisions based on environmental sustainability, this study draws a comparison between two specific FLWPR solutions (scenarios 1 and 2) and a baseline scenario (scenario 0). This section examines the results of a comparative LCA of these scenarios using the EF v3.0 method. Results prove the usefulness of this LCIA method gaining knowledge through cross-sectoral assessments, modeling, and scenarios. In addition, the assessment intends to demonstrate that this knowledge can be used to make good decisions such as detecting the effective preventive measure with the lowest environmental impact value. Moreover, this data can be used to detect hotspots for planning actions, assessing corrective solutions, and suggesting improvements.

The application of LCA (AENOR, 2006a) consists of four major steps, (i) goal and scope definition; (ii) life cycle inventory analysis; (iii) life cycle impact assessment, and (iv) life cycle interpretation. The assessment was carried out using the SimaPro 9.4.0.3 software and Ecoinvent 3, Agri-footprint 3, AGRYBALYSE and EF Database 3.1. databases.

4.1. A comparative LCA of FLWPR actions

4.1.1. Goal and scope definition

The goal of this LCA is to prove how the EF v3.0 method can be useful to conduct a comparative assessment of FLWPR actions and to share appropriate knowledge to stimulate the decision-making process. To this end, under hypothetical scenarios, two specific food loss prevention actions are modeled and assessed using the selected method. Furthermore, a baseline scenario where no action takes place is considered.

The fresh tomato supply chain was selected for this study. In this context, both selected prevention actions are based on the use of potential fresh tomato waste (tomato that is still fit for human consumption but cannot be sold) from a retailer as raw material to elaborate some new product intended to be sold again in the retailer. The difference between actions lies in the industrial processes performed; thus Action 1 is focused on producing dehydrated tomato soup and Action 2 offers the alternative of transforming tomato into juice. The estimated quantity of the non-saleable tomato (potential fresh tomato waste) determined by the retailer is 3% of the total stock. The declared unit of all assessments is 1 kg of fresh tomato to enable the subsequent comparison between actions. Fig. 4 illustrates the system boundaries of both prevention actions (scenarios 1 and 2) and of the reference situation (scenario 0) when no FLWPR action is carried out and the tomato waste is sent to composting. This End-of-Life (EoL) scenario was selected as a hypothetical FLW destination. Fresh tomato, dehydrated tomato soup, and tomato juice production are within the boundaries. Transport from field to retail (551 km), from retail to manufacturing plants (of dehydrated tomato soup and tomato juice, 22 km and 400 km respectively), from manufacturing plants to retail (same distances that from retail to manufacturing), and from retail to composting plant (15 km) are also within the boundaries. Refrigeration at retail, transport from retail to consumer, and household activities are excluded. The geographical area considered in this LCA is Spain.

4.1.2. Life Cycle Inventory (LCI)

Background data to quantify all the environmentally relevant flows that compose the modeling[2] of both actions and scenario 0 are obtained from four libraries available on SimaPro 9.4.0.3. e.g., Ecoinvent 3, Agri-footprint 3, AGRYBALYSE and EF Database 3.1. Modifications were made to the datasets referring to a different geographical area than that of this study to adapt them to Spain.

4.1.3. Life Cycle Impact Assessment (LCIA)

This stage was calculated by using the EF 3.0 Method (adapted) V1.03 / EF 3.0 normalization and weighting set available on SimaPro 9.4.0.3. Table 3 presents the results in μPt obtained from the aggregation of all the flows from the LCI and quantification of the available impact categories. The first column presents the names of the sixteen impact categories available for the EF v3.0 method. The second column shows the environmental impact values of farming 1 kg of fresh tomato including transport from field to retail. The remaining columns represent the environmental impacts of the implementation of FLWPR actions themselves (scenario 1 and scenario 2) including industrial processes, transport of 0,03 kg of tomato from retail to production plant and 0,008 kg of dehydrated soup or 0,017 kg of juice (depending on the scenario) back to retail; and of the biowaste treatment (industrial composting) including transport of 0,03 kg of tomato waste to composting plant, in case of no action is taken (scenario 0).

Fig. 5 and Fig. 6 show the environmental impacts associated with each of the three scenarios considered. To obtain these values, the impacts of farming 1 kg of fresh tomato are added separately to the impacts associated with the implementation of each action, including transport (no action, action 1, and action 2) (see Table 3). In this way, the burdens of farming the consumed fresh tomato and the not-consumed fresh tomato, together with the impacts of the process carried out to handle this not-consumed fresh tomato (composting, dehydrated soup, or juice) are represented together. A single score (see Fig. 5) enables us to know the overall environmental impact of each of the three scenarios while the weighted results presented by impact category (see Fig. 6) are highly useful to detect hotspots.

4.1.4. Life cycle interpretation

At first glance at the single score, scenario 1 has a higher overall environmental impact value followed by scenario 0, being scenario 2 the one with the lowest overall environmental impact (see Fig. 6). These

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[2] Modeling parameters are available at http://hdl.handle.net/10234/205260.

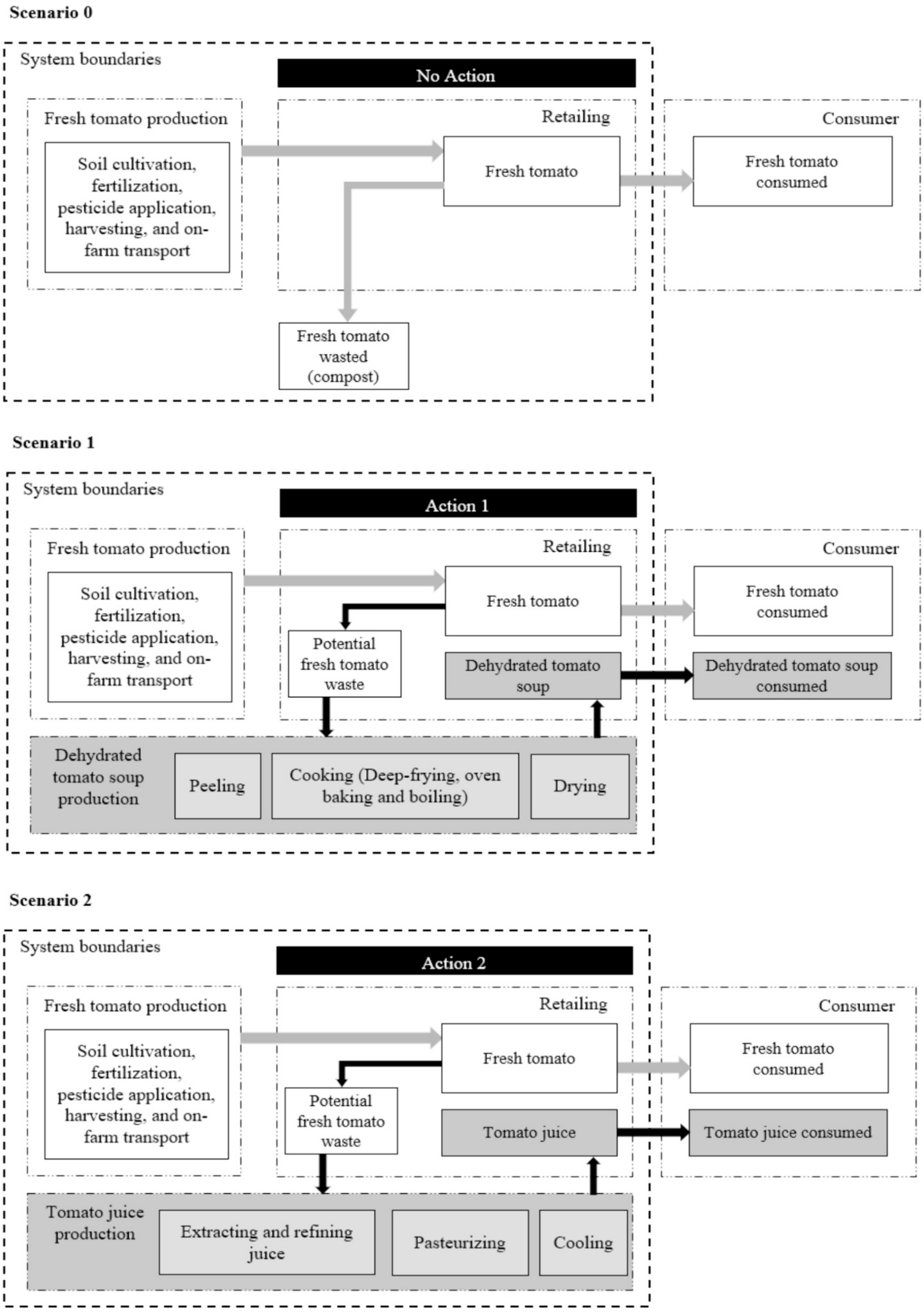

Fig. 4. System boundaries. Source: own work.

differences are mainly due to the environmental impacts of the industrial processes performed in each action where the production of juice has considerably lower impacts than the production of dehydrated soup or the biowaste composting. Although the transport process in action 2 has substantially higher environmental impacts than the ones of action 1 and "no action" due to the longer transport distance, this variation is not sufficient to offset the large difference in the production stage (see Table 3).

Weighted results also allow us to compare across all the impact categories to detect the most problematic hotspots. In all scenarios, the freshwater ecotoxicity category is the main hotspot followed by water use and climate change, all of them due to the fresh tomato farming. Only in the case of freshwater ecotoxicity, particulate matter, acidification, and terrestrial eutrophication, the impacts are higher in scenario 0, due to the composting stage (see Table 3). In the remaining impact categories, values are higher for scenarios 1 and 2, being climate change and fossils resources use the most remarkable due to the production of dehydrated soup (in scenario 1) and transport (in scenario 2). It is also worth noting that the value of the impact on water use in the composting stage is negative, which can be interpreted as environmental gains on water use due to this process.

Comparing scenarios 1 and 2, the highest variations can be observed in water use and fossil resources use, both substantially more elevated in the case of scenario 1 due to the process of producing the dehydrated soup which has a considerably higher environmental impact, especially on the category of fossil resources use. In general, all the impact categories have higher values in scenario 1, except for the particulate matter, which is slightly above in scenario 2 due to the longest transport distance. Although particulate matter in the production of dehydrated soup is considerably higher than in the juice production, transport distances

Table 3
LCIA single score and weighted results with EF 3.0 Method (adapted) V1.03 / EF 3.0 normalization and weighting set. Unit: μPt. Source: own work based on data calculated using SimaPro 9.4.0.3.

			No Action		Action 1		Action 2	
	Impact categories	Fresh tomato farming	Industrial composting	Transport	Dehydrated tomato soup production	Transport	Tomato juice production	Transport
Single score		97,822	13,322	1,909	19,219	0,575	0,751	10,454
Weighting	Climate change	13,689	1,728	0,499	4,099	0,187	0,082	3,398
	Ozone depletion	0,073	0,005	0,005	0,013	0,002	0,001	0,036
	Ionizing radiation	0,339	0,031	0,014	1,113	0,007	0,003	0,122
	Photochemical ozone formation	1,946	0,135	0,222	0,663	0,020	0,010	0,369
	Particulate matter	13,216	1,759	0,408	0,928	0,088	0,029	1,597
	Human toxicity, non-cancer	1,359	0,040	0,008	0,192	0,007	0,004	0,123
	Human toxicity, cancer	2,342	0,042	0,003	0,138	0,003	0,002	0,057
	Acidification	4,817	2,502	0,135	1,502	0,023	0,018	0,414
	Eutrophication, freshwater	1,839	0,118	0,006	0,911	0,008	0,007	0,147
	Eutrophication, marine	1,603	0,155	0,074	0,468	0,006	0,008	0,114
	Eutrophication, terrestrial	3,007	2,055	0,112	0,569	0,010	0,011	0,173
	Ecotoxicity, freshwater	20,338	3,972	0,066	1,582	0,038	0,118	0,698
	Land use	0,585	0,038	0,004	0,107	0,007	0,007	0,134
	Water use	16,122	−0,019	0,002	1,926	0,003	0,379	0,047
	Resource use, fossils	8,622	0,478	0,334	4,306	0,139	0,051	2,526
	Resource use, minerals and metals	7,925	0,285	0,018	0,702	0,027	0,021	0,499

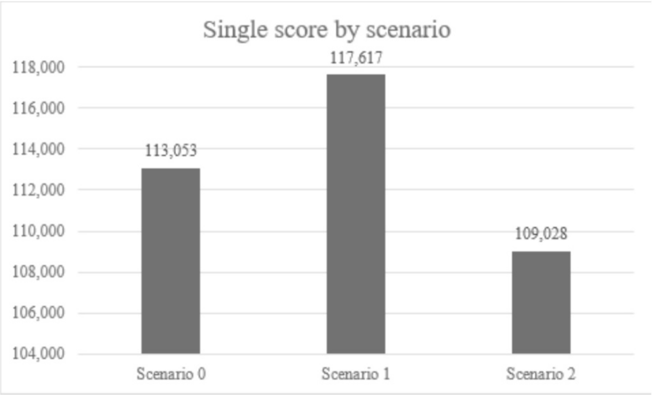

Fig. 5. Single score results of each scenario. Source: own work.

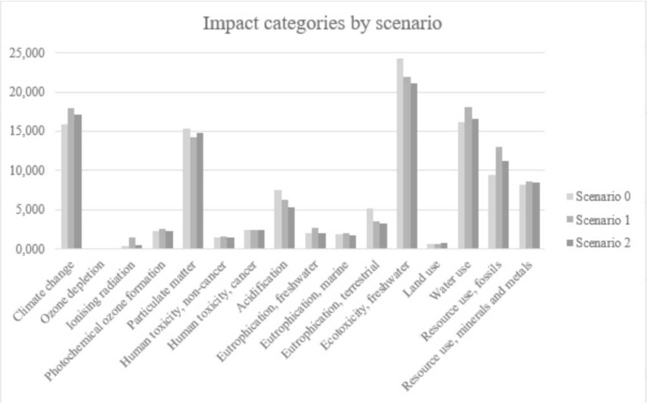

Fig. 6. Weighted results by impact categories of each scenario. Source: own work.

of scenario 2 contribute to the higher overall impact on particulate matter in the latter scenario. This offsetting only occurs in the mentioned category, although for all impact categories production impacts are higher in scenario 1 and transport impacts are far bigger in scenario 2. This is due to the considerably higher impacts associated with the production stage in scenario 1 that offset the lowest impacts on transport in this scenario compared to scenario 2 for the other fifteen impact categories.

5. Conclusions

The food value chain is responsible for significant environmental pressures. These figures raise the problem of FLW and reflect the urgent need to address it. However, the design and implementation of FLWPR actions is a complex issue to be tackled. The main threats are misinformation and a lack of knowledge concerning its sustainability impacts.

Environmental risks pose a serious and pressing problem in the current and future world (World Economic Forum, Marsh McLennan, and Zurich Insurance Group, 2023). For this reason, the present study focused on the analysis of the environmental dimension of sustainability. In this line, Life Cycle Assessment (LCA) appears as the main approach to evaluate the environmental impacts of food systems and FLWPR actions. The mapping of relevant EU research and innovation projects and the analysis of previous research show that the most used LCIA methods in this kind of research are the ReCiPe 2008, IMPACT 2002+, ReCiPe 2016, CML 2001, and EF v3.0.

One of the main outputs of this paper is to improve the comparability of FLWPR actions and to accelerate its continuous improvement processes. This paper has sought to advance in the previous literature that focused on the comparison of LCIA methods for the environmental impact results they provided. This advancement was reached by pointing out that the selection of the most suitable LCIA method to secure this improvement should be based on two essential requirements: (i) the possibility of conducting the assessment from a midpoint level, and (ii) the availability of weighting factors. One of the novelties compared to previous studies is to start by laying down a set of key requirements to ensure that the LCIA assesses the environmental implications of FLWPR actions in the most optimal way to achieve the goal set, rather than starting by exploring the environmental impacts of a specific product or impact category. After analyzing the previously identified LCIA methods with these requirements it is possible to state that the EF v3.0 method is the most suitable to achieve the goals set in this study.

Once a theoretical approach is adopted, this paper provides an empirical analysis of the whole LCA process and its suitability to assess the environmental sustainability performance of FLWPR actions. Two hypothetical FLWPR actions based on technological solutions and a baseline scenario where no action is taken were simulated. These actions consist of transforming fresh tomato, which is still fit for human consumption but not saleable, into dehydrated tomato soup in Action 1 and into tomato juice in Action 2, to avoid its wastage. This LCA aimed to show the usefulness of the EF v3.0 method to advance in the comparability of FLWPR actions in terms of environmental sustainability and to boost the continuous improvement process through the identification of hotspots.

The results of this comparative environmental LCA indicate that performing the environmental assessment with the EF v3.0 may soften the selection of the best FLWPR action providing the overall environmental impact in a single score, which allows a general comparison of actions, and the weighted results, which allows to analyze the values of each of the impact categories knowing its relative contribution to the whole environmental impact. This information can be also crucial to identify the improvement potential of the selected action and to include the system feedback for the continuous improvement process.

However, the approach of this paper presents some challenges. Although scientific literature was considered all along this research, a systematic review to identify LCIA methods was focused on work done in previous European research projects. The authors considered that this was an optimal manner to identify the most used LCIA methods to assess FLWPR actions due to the high commitment and effort that the European Commission is demonstrating regarding this issue. However, there exists the possibility of having overlooked some other LCIA methods, for example, some that are more commonly used outside the EU.

The case study was based on hypothetical information and assumptions, thus results of the impacts of the same actions in real scenarios could vary slightly form the ones obtained in this research. Moreover, just one scenario of waste treatment was modeled. Different EoL alternatives such as landfill or anaerobic digestion could offer different results which also affects the decision-making processes. However, none of these limitations affect the effectiveness of the selected LCIA method to detect hotspots, and consequently, neither does it affect the decision as to which LCIA method is the most appropriate for the objectives set in this research. The case study was focused on one kind of food product (tomato) to assess the effectiveness of the LCIA method in achieving the goals proposed. Future lines of this research should expand the comparison framework of FLWPR actions to also include different kinds of food products, taking as a basis the research performed in the present study.

Besides that, to be coherent with the first sustainability principle (Muñoz-Torres et al., 2018), economic and social dimensions should also be considered and balanced during the assessment of FLWPR actions. The introduction of these new variables significantly complicates the decision-making process because hotspots detected during the environmental assessment could conflict with those in the other two assessments, causing offsets. For this reason, further research is needed to integrate environmental, social, and economic assessments in the same framework to solve these difficulties and clarify the decision-making processes in the field of FLWPR actions. The case study performed on this research can be taken to illustrate this hurdle. Attending to environmental impacts, Action 1 is less likely to be selected as the best option due to its higher environmental impacts both in terms of single score and weighted results. However, there is a possibility that in social or economic assessment it may have more favorable results. At this point, hotspot identification using EF v3.0 becomes crucial because it can be used to plan and assess improvement measures linked to the categories with the highest improvement potential that could reduce the overall environmental impact of Action 1, which could be highly useful in case this action has better social or economic results than the alternatives. However, it is important to be aware that this improvement in terms of environmental impact reduction, in turn, could have new repercussions from an economic and social perspective, thus emphasizing the need to be active in the continuous improvement processes in the three domains.

To overcome this shortcoming, it would be interesting to explore a better way to successfully integrate the social and economic impact assessment approaches, together with the environmental assessment, in a single user-friendly monitoring tool that enables a standardized FLWPR action comparison to provide stakeholders with the proper information to facilitate their decision-making process towards a more sustainable agri-food system.

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Author agreement statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

All the authors have participated in the Conceptualization, Investigation, Methodology, Formal analysis, Writing, Reviewing and Editing of the research carried out.

We understand that the Corresponding Author is the sole contact for the Editorial process. He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

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

Aditional data available on http://hdl.handle.net/10234/205262 and http://hdl.handle.net/10234/205260

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