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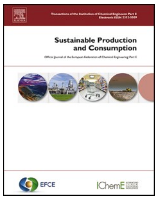

Review Article

Integrating product-focused life cycle perspectives in the fresh food supply chain: Revealing intra- and inter-organizational views

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ABSTRACT

Perishable food products generate significant waste and consume a high amount of energy due to quality and safety maintenance requirements, stressing supply chains and highlighting the need to improve their efficiency and environmental sustainability. Integrating the life cycle perspective in the fresh foods supply chains can provide valuable insights for improving environmental sustainability. The primary objective of this study is to show how each actor in the fresh food supply chain can reduce its environmental impact by using a life cycle perspective. It also reveals the environmental concerns created by perishable products and current practices by using a life cycle perspective that can be integrated into the supply chain. The study also explores how the product-focused approach of the life cycle perspective can be integrated across the fresh foods supply chains to reveal both intra- and inter-organizational practices. By analysing 40 different studies, this research explores the life cycle–based aspects and the environmental concerns associated with fresh food agricultural products and identifies the practices that can be adopted by supply chain actors to manage these concerns. These practices range from individualized (can be put in place at a function and/or organization level) to highly interconnected (can be applied only through cooperation with other parties along the supply chain), creating dyadic, triadic or extended network cooperation. It is found that these actions can be translated into three dimensions: technological, related to the use of efficient and optimized technologies; operational, related to the reduction of raw materials consumption, distribution configurations and the improvements of crops; and management, related to monitoring, improvement targets, and local supply chain configurations. Future research could expand to include targeted literature reviews on underexplored areas such as biowaste generation and food waste management along the supply chain.

1. Introduction

Agrifood systems comprise a wide range of actors and their activities in the primary production of food and non-food agricultural products, including storage, aggregation, post-harvest handling, transportation, processing, distribution, retailing, disposal and consumption. Within agrifood systems, food systems comprise all food products that originate from crops and livestock, forestry, fisheries and aquaculture (FAO, 2021). The increase in food supply, also determined by changes in lifestyle and consumption habits, has led to an exponential increase in the consumption of resources and energy, increasing the environmental impact associated with production, processing, distribution, utilization and even disposal (Clark et al., 2022; Daniel et al., 2022; Shafiee-Jood and Cai, 2016). These changes not only pose environmental challenges but also significantly impact the business landscape and social dynamics (Yang et al., 2023).

Food systems, particularly those of perishable goods, directly influence local economies and employment, shaping the livelihoods of communities. The necessity for spatial proximity in production due to product perishability fosters the development of localized production hubs, giving rise to environmental, economic and social facets (Abbas et al., 2023).

The high perishability of food products leads to significant waste generation and energy consumption, stressing food supply chains and making it imperative to improve their efficiency and environmental sustainability (Ghezavati et al., 2017; Gupta et al., 2023; Matos and Hall, 2007). In terms of energy consumption, food supply chains are responsible for a substantial portion of global energy use. For instance,

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equipment used in the food cold chains accounted for nearly 261 million tons of CO_2e emissions in 2017, reaching 1004 million tons, including emissions from food loss and waste (UNEP and FAO, 2022; International Institute of Refrigeration, 2021).

A supply chain is a complex network involving multiple organizations connected through product, service, financial and informational flows (Mentzer et al., 2001; Carter et al., 2015). The perishability of products such as fruits, vegetables, dairy, meat and marine foods necessitates effective time management and minimal processing to preserve quality across the supply chain (Stonehouse and Evans, 2015; Lee et al., 2020; Delgado et al., 2023). The market's emphasis on fresh products demands stringent maintenance of the cold chain, which encompasses various energy-intensive processes. Products of crops, such as fresh fruits and vegetables, are perishable high-value products (FAO, 2021), which are quickly placed on the market, sealed and packaged in compliance with the maintenance of the cold chain (de Carvalho et al., 2022; Delgado et al., 2023). Failure in these processes can lead to significant economic losses, productivity downturns and increased food waste (Giannakourou and Tsironi, 2021; Mistriotis et al., 2016). For this reason, pre-cooling and freezing systems, cold storage warehouses, refrigerated trucks, freezers, display cases, household refrigerators and other energy-intensive equipment are all used in the cold chain, highlighting the need of advanced technologies and efficient operational practices across the supply chain of perishable high-value products, such as fruits and vegetables.

Recognizing environmental burdens is imperative to developing an integrated sustainability strategy. Moving from fragmented actions to more holistic solutions (Carter and Rogers, 2008; Chen et al., 2022) necessitates an understanding of the entire supply chain from cultivation to consumption (Ingrao et al., 2021; Pagell and Shevchenko, 2014). Integrating the life cycle perspective within a supply chain can provide valuable insights into its environmental sustainability. It allows businesses to identify environmental hotspots, optimize processes and make informed decisions to reduce the overall environmental impact of their products. Understanding the life cycle's environmental implications can influence the sourcing of raw materials, production processes, transportation methods and disposal decisions, addressing the need to adopt a systematic view and go beyond viewing the supply chain as a closed system disconnected from its environment (Wieland, 2021). Moreover, considering the life cycle makes it easier to benchmark and optimize the environmental performance of perishable food products. It identifies effective improvement strategies and prevents the shifting of burdens across the supply chain (Hellweg and Milà i Canals, 2014). By adopting a ‘cradle-to-grave’ approach, life cycle thinking integrates environmental considerations into decision-making processes throughout the supply chain and incorporates sustainability concerns (Matos and Hall, 2007).

Consequently, this research endeavours to explore the interconnections between the supply chain of perishable high-value products, such as fruits and vegetables, and a life cycle perspective, focusing on all parties involved in fulfilling customer demands. Our research is groundbreaking in two key aspects: it illustrates the benefits of a life cycle perspective for all supply chain actors in decreasing environmental effects, and it identifies strategic solutions to avoid the displacement of environmental burdens within the supply chain (Hellweg and Milà i Canals, 2014; Poore and Nemecek, 2018). The research addresses the following questions:

RQ1. What are the environmental concerns caused by fresh food agricultural products, and what improvement practices emerging from a life cycle perspective can be integrated into their supply chain?

RQ2. How can the product-focused life cycle perspective be integrated across the fresh food agricultural products supply chain to reveal both intra-organizational and inter-organizational practices?

To answer these questions, the life cycle perspective is employed as a foundational framework, enabling the identification of the most impactful phases of the product life cycle and the main contributions of each phase (Sala et al., 2013).

2. Methods

To answer the research questions, a systematic literature review was performed following the steps proposed by Durach et al. (2017). The framework to integrate life cycle thinking in the supply chain perspective for perishable goods, such as fruits and vegetables, is presented in Fig. 1. The figure shows that the life cycle perspective and the supply chain perspective can enhance each other, making the product view intra- and inter-organizational and providing a new perspective that allows the actors along the supply chain to improve their environmental impact using life cycle thinking.

2.1. *Required Characteristics of Primary Studies*

Since the life cycle perspective allows us to identify the most impactful phases of a product's life cycle and the main contributions of each phase, this literature review begins by analysing studies that have applied the main life cycle methodologies focused on environmental sustainability, recognized in the scientific literature, namely, the Life Cycle Assessment (LCA) and the Carbon Footprint (CF) methodologies (Hellweg and Milà i Canals, 2014; Notarnicola et al., 2012).

According to the research questions, only LCA and CF studies regarding perishable fresh food products (fruits and vegetables) are included in this research, using as a unit of analysis each scientific article published in journals, written in English, and retrieved through the selected keyword.

2.2. *Baseline Sample*

To retrieve a sample of potentially relevant literature, research was performed in the ISI Web of Knowledge database using the following keywords: ‘supply chain’ AND (cold OR fresh OR chilled OR frozen OR ‘fresh cut*’ OR fresh-cut*) AND (‘life cycle assessment’ OR lca OR ‘carbon footprint’) AND (fruit OR vegetabl*). This search led to the discovery of 88 articles.

2.3. *Synthesis Sample*

Then, a selection of the baseline sample was conducted to identify relevant studies according to exclusion criteria and select only those dealing with fresh products such as fruits and vegetables and with a life cycle perspective application, as shown in Table 1. To avoid excluding any relevant studies, no temporal horizon was selected. Only studies published in journals were included in the sample, leading us to 83 articles that were analysed based on their title and abstract, allowing us to exclude another 41 studies. After a detailed relevance test that went beyond the papers' titles and abstracts, two more studies were excluded, leading to a final sample of 40 studies.

Overall, 40 articles published since 2007 were found. Most of the selected articles were published during the last 10 years, showing that although interest in this topic was weak for several years, it is growing. Altogether, 25 different journals were involved, demonstrating that the topic is transversal among journals about agriculture and environmental and territorial management. It also shows that the topic is studied in several geographical areas.

The next steps involved analysis and synthesis of the selected literature.

2.4. *Literature Synthesis*

The 40 articles included in the analysis were examined separately to identify aspects and concerns. Next, they were crossed to reveal the improvements that can be made by actors in the supply chain of fresh

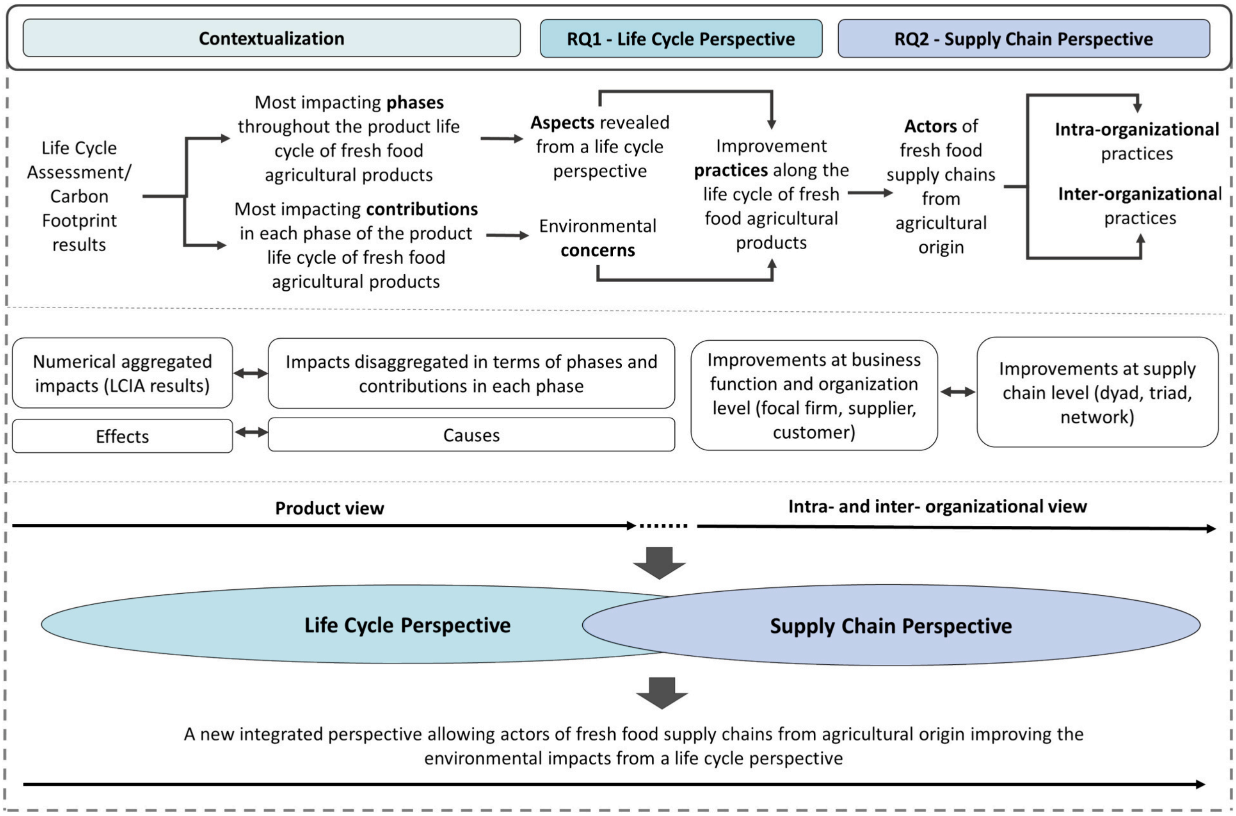

Fig. 1. Framework for integrating the life cycle perspective in the fresh food supply chain of products.

Table 1
Procedure for the inclusion of the studies in the analysis.

Details of studies identified	Number
Studies identified by the combination of keywords adopted	88
Studies not considered (because they were not published in journals)	5
Studies excluded after title and abstract analysis (because they were not relevant in terms of life cycle perspective application or analysed products)	41
Studies excluded for full paper analysis (because they were not relevant in terms of life cycle perspective application or analysed products)	2
Studies included for analysis	40

food agricultural products.

The Life Cycle Impact Assessment (LCIA) results of each LCA/CF study were analysed to capture the most impactful phases of the life cycle and the contributions of specific material or immaterial input and output flows (Finnveden et al., 2009). The LCIA results were usually reported in relative terms through a percentage value, thus facilitating the identification of the most impactful contributions regarding the system boundaries, as performed, for instance, by Bin et al. (2023). In cases where the LCIA results were reported without a percentage value, the relative contributions were calculated (e.g. Bortolini et al., 2016; Bortolini et al., 2018). To avoid the exclusion of relevant studies, all articles, regardless of the LCIA method, were included and analysed, thus also considering those that focused only on climate change.

Starting from an aggregate dimension of environmental impacts, expressed as LCIA results in the selected LCA/CF studies, and analysing the disaggregated dimensions of the impacts in terms of causes (phases and contributions) and effects (modification on a specific environmental impact category), it was possible to obtain aspects and concerns.

After studying the most impactful phases in the different studies and linking them to the different actors/parties along the fresh food supply chain from the agricultural origin, a map of the main environmental aspects associated with the products was developed.

This analysis was conducted based on the 40 studies through the following steps. First, we created a list of processes revealed inductively from the studies that represent the life cycle phases of a fresh food product from agricultural origin ordered from upstream to downstream. Next, we created a list of processes that represent other phases of the life cycle revealed inductively from the studies and which can be at different points of the life cycle recurrently. We then elaborated on analytic categories and assembled them into aspects associated with the life cycle perspective. Looking at the impact contributions, the main environmental concerns were identified, expanding the supply chain framework of aligning products and supply chain features to food producers, non-producers, businesses and consumers (Gómez and Lee, 2023). The revealed aspects were then assigned to the different supply chain actors, and the main environmental contributions were used to reveal the environmental concerns (Seuring, 2004; Seuring and Müller, 2008). The improvement practices that can be applied by the different actors along the supply chain were extracted based on the suggestions or future perspectives proposed in the articles analysed, thereby answering RQ1.

The improvement practices revealed from the literature were interpreted based on the supply chain practice view (Carter et al., 2017). According to this, practices can span from the individual level through the function level, overcoming the organization's boundaries and extending to other supply chain partners, creating dyads and beyond. The improvement practices were analysed on an organizational or supply chain level and classified as intra-organizational and inter-organizational. Inter-organizational practices differ from intra-organizational practices as they require mutual efforts from two or more firms to be effective (Carter et al., 2017; Terpend et al., 2008; Zimmermann and Foerstl, 2014). By analysing and classifying the practices, it is possible to shift from a product view typical of the life cycle perspective to an intra- and inter-organizational view, including the improvement practices for each supply chain actor, thereby addressing RQ2.

By employing inductive reasoning to analyse the 40 articles, we observed the existence of integrated practices combining life cycle perspectives with supply chain inter-organizational interactions. This iterative analysis, supported by a structured coding system and bolstered by comparisons within different studies, reduces the likelihood of missing alternative explanations, thus strengthening the credibility of the results (Durach et al., 2021). Through this process, we categorized the research papers based on practices, processes and perspectives – technological, operational and management – that emerged during the coding.

The extracted coding scheme is described in Section 3 with a descriptive overview of the reviewed literature.

3. Results

Our analysis of the selected articles reveals that the life cycle perspective is applied in both LCA and CF methodologies, sometimes even in combination (Pérez-Neira and Grollmus-Venegas, 2018; Rufí-Salís et al., 2020). However, we also find the application of the water footprint methodology (Subramaniam et al., 2020) and the development of a life cycle inventory without impacts results (Arshad et al., 2019).

Different system boundaries were applied in the studies. Particularly, studies that analysed the possibility of improving the packaging neglected the content and its life cycle in favour of a more deepened study on the packaging. They analysed the packaging life cycle from the extraction of raw materials to its disposal and thus applied a complete life cycle perspective by considering the package as a unit of analysis. Others applied a complete life cycle perspective by considering the fresh food products, from their cultivation (including seed production) to their disposal, as a unit of analysis (e.g. Loiseau et al., 2020). In some cases, the life cycle perspective was applied from cultivation to the point of sale or to the point at which it was consumed (e.g. Munasinghe et al., 2019), neglecting the package's end-of-life. This was done because researchers were more focused on the impact of the product than on the combined impact of the product and its packaging. In other cases, the system boundaries only included a limited number of life cycle stages, such as distribution (e.g. Burek and Nutter, 2020; Camilo et al., 2020). These studies were included in this research because, even if the unit of analysis was the distribution, the impact was analysed using a life cycle perspective.

The type of study (LCA/CF) and the perspective used as stated in the articles analysed are reported in Table 2, along with the processes included in the system boundaries. Different products were studied, some more so than others. These products included tomatoes (e.g. Camilo et al., 2020), potatoes (e.g. Caracciolo et al., 2018), palm oil (e.g. Arshad et al., 2019), lettuce (e.g. Rufí-Salís et al., 2020) and apples (e.g. Frankowska et al., 2019). Some studies did not specify which products they examined, especially those focused on packaging, transportation and distribution (Table 2).

The analytic list of life cycle–based processes that were revealed inductively from the studies is represented in Fig. 2. This figure displays the life cycle phases of a fresh food product from its agricultural origin, ordered from upstream to downstream, and the analytic categories assembled into aspects associated with the fresh food products' life cycle.

Among the different aspects that emerge from our analysis, the most prominent one is logistics (transport and distribution). In some cases, it is the only aspect investigated (e.g. Bortolini et al., 2016), whereas, in others, it is one of the stages of the life cycle taken into consideration (e.g. Frankowska et al., 2019). The next most analysed aspects are processing and packaging, followed by cultivation. The aspects included in a limited number of studies are retailing, consumers and biowaste generation, reflecting the differences in system boundaries used by the different scholars. These differences in system boundaries, which are summarized in Table 2, influence the relative impacts among different processes. The impacts of different products on the supply chain could be associated with different phases, depending on the scope of the study and the number of processes it included.

A synthesis of how the different life cycle–based aspects are addressed in the analysed studies and the LCIA relative contribution is reported in Table 3.

For instance, in the studies by Camilo et al. (2020) and Sanderson et al. (2019), distribution – particularly via aircraft – had a greater environmental impact, but so did inefficiently managed temperature-controlled transport. In the case developed by Dong and Miller (2021), the main causes of greenhouse gas (GHG) emissions were cold storage in warehouses and during transportation. However, the study focused on distribution and neglected other aspects. This also occurred in the study by Frankowska et al. (2019), where cold conservation was an important contribution mainly for products that were stored for longer times (Bin et al., 2023). In other studies focused on logistics, energy use for refrigeration during storage and retailing, along with refrigerant emissions, were the major sources of GHG emissions in distribution centres and supermarkets (Burek and Nutter, 2020). In their LCA study, Loiseau et al. (2020) used a cradle-to-grave perspective to highlight that the logistics phase contributes significantly to the supply chain's impact and that there is still room for improvement in supply chain performance. Stone et al. (2021) demonstrated the importance of both the scale of production and the distance between producers and consumers. They also showed that mid-scale (commercial, local) and small-scale (home garden) vegetable production were associated with much lower environmental outputs. However, the results of the research by Pérez-Neira and Grollmus-Venegas (2018) showed that the local supply chain is a low-energy-impact option for the production and supply of fresh vegetables at the urban level, especially when distribution is done directly.

Sometimes, transportation can be the main contributor to the impact concerning some specific categories, such as climate change, energy consumption, terrestrial acidification, marine eutrophication and fossil depletion. Whereas, for other categories, such as freshwater eutrophication, ecotoxicity, metal depletion and water deprivation, the main contribution is cultivation (Payen et al., 2015). Similar considerations were revealed by Parrot et al. (2022), who found that most environmental impacts were caused during transport (depending on the type of vehicle used and the distance) or processing stages, particularly for dried fruit.

In Vigil et al. (2020), the higher impact was due to packaging production when packaging production and its end-of-life were included in the assessment. However, if the evaluation was extended to cultivation, the higher impact was attributed to agricultural production, followed by package manufacturing and vegetable sanitation. If a study only focused on packaging, the higher contributions could be due to packaging disposal or transportation depending on the type of packaging (Accorsi et al., 2014).

Studies on cultivation reveal that the agriculture stage is the higher contribution mainly due to fertilization (Choo et al., 2011), but others demonstrated in their case studies that irrigation is one of the most impactful processes during cultivation and vegetable sanitation (Milà i Canals et al., 2010), along with the crop production of fresh fruit (Subramaniam et al., 2020). Pérez Neira et al. (2018) calculated that the energy consumption, infrastructure and fertilizers were the main impact sources in the supply chain of heated and unheated tomato crops. However, farm production, transport and packing were the main contributors when the study was extended to the entire system, demonstrating that the significance of the contribution to the impacts is linked to the wideness of the system boundaries.

In other cases, important contributions were due to seasonal workers' transportation to reach the cultivation sites (Sanderson et al., 2019), the use of fertilizers (Munasinghe et al., 2019) and the use of plastic for the construction of greenhouses (Hu et al., 2019).

Based on the LCIA relative contribution revealed from the studies and reported in Table 3, it was possible to link the life cycle–based

Table 2
List of studies included and their main features.
Note: End-of-life (EOL), Life Cycle Assessment (LCA), Carbon Footprint (CF), Greenhouse gases (GHG).

Reference	Type of study	Processes included in the system boundaries	Product analysed
Accorsi et al., 2014	LCA methodology is used to evaluate the CF associated with the life cycle of packages in a distribution network	Packaging production, distribution and its EOL	Packaging
Arshad et al., 2019	Life Cycle Inventory	Cultivation, palm oil production, packaging, distribution, sale	Palm oil
Battini et al., 2016	Environmental assessment using LCA	Packaging production, distribution and EOL packaging	Packaging
Bin et al., 2023	LCA calculated on the basis of PAS 2050	Cultivation, packaging, production, distribution, sale	Fruits and vegetables
Bortolini et al., 2016	CF	Production and distribution	Potatoes, apples, pears, Brussels sprouts, oranges, tomatoes
Bortolini et al., 2018	Environmental impact on climate change	Packaging production, use and its EOL	Packaging
Burek and Nutter, 2020	LCA to calculate the climate change impact, non-renewable energy use and water scarcity	Distribution and sale	Not specified
Camilo et al., 2020	LCA	Distribution	Tomatoes
Caracciolo et al., 2018	Environmental impacts with LCA	Distribution	Potatoes
Choo et al., 2011	LCA considering the share of GHG gas contribution	Cultivation, palm oil production, refineries, biodiesel plants and the use of biodiesel in diesel engine vehicles (transportation)	Palm oil
Delahaye et al., 2023	LCA considering human health, quality of ecosystems, climate change and resources	Packaging, distribution	Packaging
Diaz et al., 2022	LCA in terms of Global Warming Potential (GWP), Cumulative Energy Demand (CED) and water scarcity based on the AWARE method	Distribution	Not specified
Dong and Miller, 2021	Lifecycle GHG emissions	Cultivation, distribution, utilization	Not specified
Du Plessis et al., 2022	Lifecycle GHG emissions	Distribution	Not specified
Frankowska et al., 2019	LCA	Cultivation, production, distribution, packaging production, sale, utilization, generation of waste	21 types of fruits and their 46 products
Hu et al., 2019	CF	Cultivation, production, distribution, packaging, utilization, disposal	Potatoes and tomatoes
Iriarte et al., 2021	CF	Cultivation, production distribution, packaging, utilization	Apples
Le Féon et al., 2023	LCA	Cultivation, production, distribution, packaging, utilization, disposal	Apples
Li et al., 2022	CF	Cultivation, production, distribution, packaging, utilization	Not specified
Loiseau et al., 2020	LCA	Cultivation, production, distribution, packaging, utilization, disposal	Apples
Lukasse et al., 2023	CF	Distribution	Fresh produce
Milà i Canals et al., 2010	Water footprint and LCA	Cultivation, production	Broccoli
Munasinghe et al., 2019	LCA, CF and energy footprint	Cultivation, production, distribution, packaging	Palm oil
Parajuli et al., 2021	LCA protocol designed for formulating the life cycle inventories	Cultivation, production, generation of waste, utilization	Potatoes and tomatoes
Parrot et al., 2022	LCA	Cultivation, production, distribution, packaging, utilization, disposal	Mango
Payen et al., 2015	LCA	Cultivation, transportation, packaging, distribution	Tomatoes
Pedreschi et al., 2022	LCA for GHG emissions and resource depletion	Distribution	Avocado
Pérez Neira et al., 2018	CF and energy footprint	Production, packaging, distribution	Tomatoes
Pérez-Neira and Grollmus-Venegas, 2018	Life cycle energy assessment and CF	Production, packaging, distribution, utilization	Not specified
Rasines et al., 2023	LCA	Cultivation, production, distribution, packaging, utilization, disposal	Broccoli
Ruff-Salís et al., 2020	LCA through the climate change indicator	Cultivation	Tomato, lettuce, spinach, chard, bean, arugula, pepper
Sanderson et al., 2019	LCA	Cultivation, production, distribution, packaging	Cherries
Savino et al., 2015	CF	Production, distribution	Chestnuts
Shabir et al., 2023	CF	Cultivation, production, distribution, packaging, utilization, disposal	Fruits and vegetables
Sim et al., 2007	LCA	Cultivation, production, distribution, packaging	Not specified
Stone et al., 2021	LCA approach focusing on GWP	Production, packaging, distribution, disposal	18 vegetables (e.g. lettuce)
Subramaniam et al., 2020	Water footprint	Cultivation, production	Palm oil
Vigil et al., 2020	LCA	Cultivation, production, distribution, packaging, utilization, disposal	Lettuce
Wu et al., 2019	LCA climate change impacts	Cultivation, production, distribution, packaging, disposal	Citrus
Xue et al., 2021	CF	Production, disposal	Tomatoes

aspects of the fresh food products to the different actors/parties along the supply chain. For instance, for the cultivation aspect, the utilization of fertilizers, mechanical operations, irrigation and energy consumption are important contributors, which, from a supply chain perspective, mainly involve suppliers and procurement departments. For packaging the materials used, shapes and shelf-life extensions are important decisions to be taken by suppliers and procurement departments. Processing is mainly dominated by the operations that consume energy (e.g. pressing and drying); logistics comprises transport, distribution and employee trips intercepting different actors along the supply chain, from

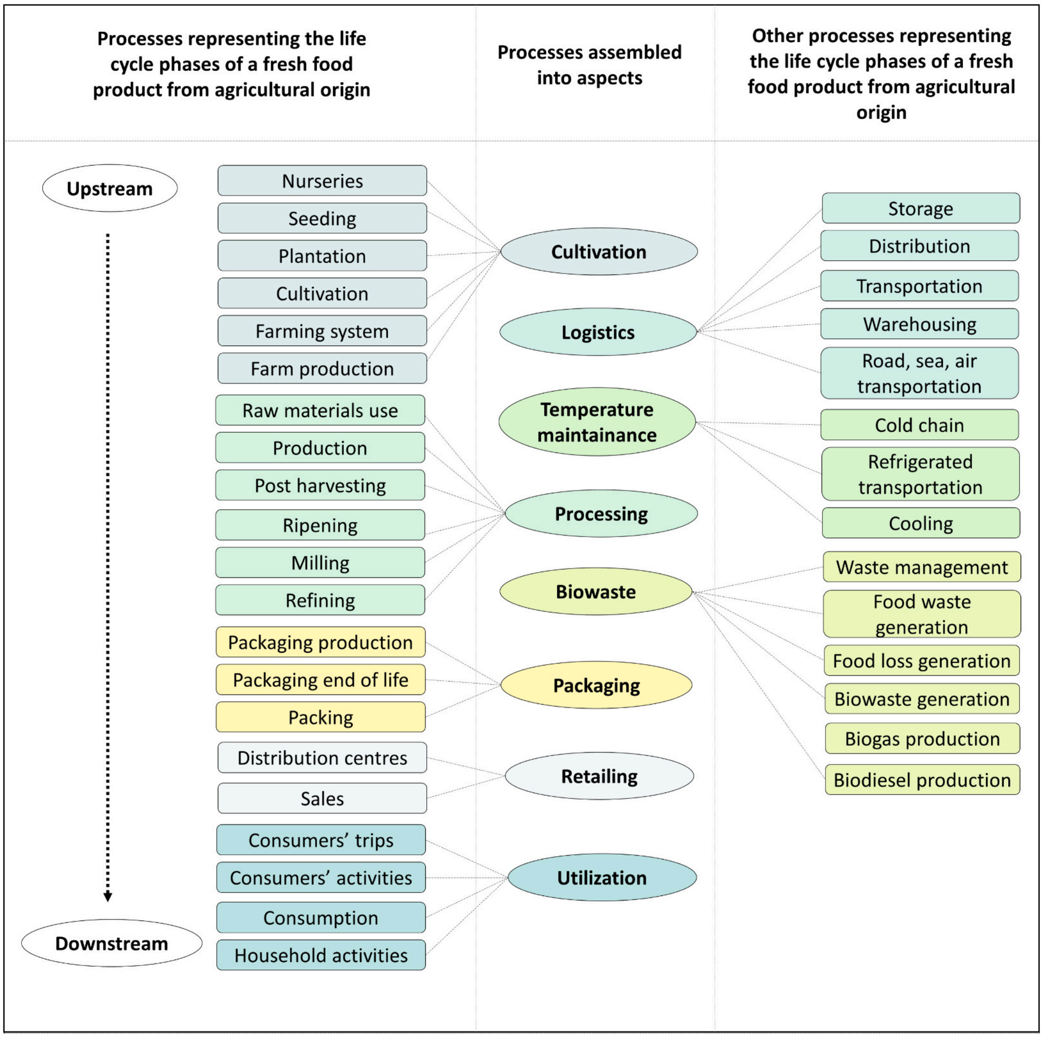

Fig. 2. Processes assembled into aspects associated with a fresh food product's life cycle.

operations to customers. Temperature maintenance encompasses the impacts associated with cooling and storage. This aspect makes an important contribution that all the actors along the supply chain should manage. Similarly, biowaste generation, which can occur during cultivation and thus involves suppliers, must be managed throughout the supply chain. The contributions associated with retailing and utilization are mainly linked to the final actors along the supply chain. Fig. 3 shows a conceptual map that examines the aspects revealed through the literature review and the actors/parties along the supply chain.

4. Discussion

This research aims to address both RQ1 and RQ2 by uncovering and applying life cycle–based improvement practices within the fresh food supply chain to mitigate environmental concerns. It also explores strategic solutions for integrating product-focused life cycle assessments within the supply chain, considering both intra-organization and inter-organizational aspects to reduce environmental impacts. Responses to these questions will be discussed in detail in Sections 4.1 (RQ1) and 4.2 (RQ2).

4.1. Improvement Practices

Improvement practices can be examined in detail through an analysis of solutions proposed from a life cycle perspective, followed by an association with different actors along the supply chain.

4.1.1. Solutions from a Life Cycle Perspective

Fig. 4 represents the crossing of environmental concerns revealed from the analysed studies and the actors/parties along the supply chain, leading to the following solutions. Regarding cultivation, one of the most challenging aspects is high water consumption (Subramaniam et al., 2020). Taking water consumption into account, differentiating between volumes used and determining various sources of supply could improve the knowledge of these aspects (Milà I Canals et al., 2010). Another way is through the limitation of fruit cultivation in highly water-stressed countries (Frankowska et al., 2019). Regardless, it is difficult to calculate the impacts associated with water consumption and related damages, to the point that current assessments may still be underestimated (Payen et al., 2015). In addition to the problems related to water resources, there are those related to energy consumption. To this end, the use of efficient technologies (Dong and Miller, 2021), such as optimized heating systems in multi-tunnel greenhouses, even in countries where the products originated, can lead to reductions in environmental impacts (Pérez Neira et al., 2018). Adequate training of workers and plans to improve agricultural practices are also useful (Le Féon et al., 2023), for instance, reducing inorganic fertilizers in favour of organic ones with precise applications and accounting for biogas capture (Choo et al., 2011). Another solution can be increasing the diversity of the systems, combining long productive crops with other value-added

Table 3
Aspects from a life cycle perspective associated with the reference studies.

Aspects	Examples of how the aspects are addressed	LCIA relative contribution obtained in the studies analysed	Reference
Cultivation	Processes are evaluated with reference to crop production scenarios, integrating environmental issues with productivity and assessing the crop yield (Parajuli et al., 2021), fertilization (Choo et al., 2011), water consumption (Milà i Canals et al., 2010), heating systems and greenhouse cultivation (Frankowska et al., 2019; Pérez Neira et al., 2018).	The major contributor to GHG emissions related to palm oil cultivation is N fertilization (49 %); nursery represents just 0.01 %. Biogas capture can affect the relative impacts of the other phases. For instance, for palm oil, plantation and nursery together represent 70 % of the impact, but without biogas capture, they represent 35 %.	Choo et al., 2011
		For different fruits analysed regarding primary energy demand, farm production accounts for 8–37 % of the total impact (cradle-to-grave); with reference to water footprint, it contributes to more than 80 %. But with reference to climate change, cultivation represents 29 % of the total impacts, as calculated with a cradle-to-grave approach. Agricultural production accounts for more than 50 % of agricultural land occupation.	Frankowska et al., 2019
		For potatoes and tomatoes, production on the farm accounts for about 66–77 % in terms of GHG emissions with a cradle-to-grave approach. Fertilizer application and irrigation both account for 6 %.	Hu et al., 2019
		The major contributor to GHG emissions in palm oil cultivation is the production stage, accounting for 60 % (the system boundaries include the processes from cultivation to utilization).	Li et al., 2022
		Cropping represents 41–76 % of the impacts calculated, including the phases of cultivation and production.	Milà i Canals et al., 2010
		On-farm production accounts for 64 % of the GHG emissions associated with tomatoes (the study includes production, packaging and distribution).	Pérez Neira et al., 2018
		Irrigation accounts for 15–30 % of climate change, photochemical ozone formation, acidification, eutrophication and resource use. Concerning water use, it accounts for 99 %. Fertilizers account for 20–40 %.	Rasines et al., 2023
		Agricultural production accounts for 50–90 % in almost all the impact categories analysed.	Vigil et al., 2020
		For tomatoes, 54 % of GHG emissions were from production (calculated including the phases of production, distribution and disposal).	Xue et al., 2021
		The agricultural production of apples accounts for about 12 % of the carbon footprint calculated with a cradle-to-grave approach. In the farm, fertilizers account for 57 % as primary (field emissions) and secondary processes (mainly fertilizer production). Electricity consumption accounts for 22 %.	Iriarte et al., 2021
		The cultivation stage contributes 9 % to water use and 93 % to land use of total impacts. Phosphate emitted into water during the cultivation stage contributes about 25 % to eutrophication (calculated for apples with a cradle-to-grave perspective). For the other categories, impacts during the cultivation stage were related directly to mechanical operations.	Le Féon et al., 2023
		The production of apples contributes 40 % to acidification, freshwater eutrophication, terrestrial ecotoxicity, agricultural land occupation and metal depletion due to fertilizers and pesticides (calculated with a cradle-to-grave perspective).	Loiseau et al., 2020
		At the plantation stage for palm oil production, the highest emission comes from fertilizer application: direct N_2O emissions (47 %) and indirect N_2O emissions from leaching and runoff (11 %) (calculated with a cradle-to-gate approach regarding carbon footprint). The second highest comes from upstream emissions related to fertilizers (35 %).	Munasinghe et al., 2019
		Tomato cultivation contributes to 37 % of the impact on climate change due to the manufacture of greenhouse components and electricity consumption for fertigation (calculated with system boundaries that include the processes from cultivation to distribution). The contribution to renewable energy use is 34 %. It is the main contributor to freshwater eutrophication, with 66 % of the impact. It contributes 39 % to terrestrial acidification. Tomato cultivation is the main contributor to all ecotoxicity impact categories and contributes 69 % of the metal depletion. Tomato cultivation is responsible for 94 % of the freshwater use over the entire tomato life cycle due to irrigation water use.	Payen et al., 2015
		Fertilizer application is most prominent in freshwater eutrophication, contributing approximately 87 % (calculated with a cradle-to-gate perspective).	Sanderson et al., 2019
Packaging	Packaging production and optimization of the packages are analysed in terms of volumes, shapes, dimensions, quality features maintenance and shelf-life extension (e.g. Accorsi et al., 2014; Vigil et al., 2020), and by combining environmental issues with predicted quality retention (Wu et al., 2019).	Single-use packaging manufacturing accounts for about 65–72 % of the total impacts in terms of climate change (when distribution and its end-of-life are included in the system boundaries); in the case of reusable packaging, the manufacturing process can account for 36–45 %.	Accorsi et al., 2014
		The manufacturing of disposable packaging accounts for about 80 % of the total impacts in terms of climate change (when its use and	Bortolini et al., 2018

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Table 3 (*continued*)

Aspects	Examples of how the aspects are addressed	LCIA relative contribution obtained in the studies analysed	Reference
		end-of-life are included in the system boundaries); in the case of reusable packaging, it can account for about 40 %.	
		In the case of PET packaging for strawberries (considering distribution), the process that has the most significant impact is the packaging production (47 %), which is calculated as a single score combining human health, quality of ecosystem, climate change and resources.	Delahaye et al., 2023
		For potatoes and tomatoes, packaging accounts for about 7–8 % in terms of GHG emissions with a cradle-to-grave approach.	Hu et al., 2019
		Packaging manufacturing accounts for 15–20 % for the categories ozone depletion, marine eutrophication, ionizing radiation and metal depletion with a cradle-to-grave approach.	Vigil et al., 2020
		Tomato cardboard packaging contributes to 17 % of the impact on climate change (calculated with system boundaries that include the processes from cultivation to distribution). The contribution to renewable energy use is 23 % and terrestrial acidification is 10 %. Packaging contributes 69 % of the agricultural land occupation.	Payen et al., 2015
Logistics	Transportation activities from cultivation sites to production sites are analysed, along with the distribution towards the retailers. Rail transportation is studied as a means to reduce GHG emissions (Caracciolo et al., 2018), and short supply chains are analysed regarding long supply chains, raising the question of up to what point short chains perform better than traditional ones (Loiseau et al., 2020; Iriarte et al., 2021). Logistics is discussed regarding packaging, highlighting the influence of short and long chains on the products' quality and safety (Pedreschi et al., 2022).	The transportation of tomatoes from the producers to the warehouses accounts for about 98 % of the total impact for all the ReCiPe categories when just distribution is included in the system boundaries; the transportation from the warehouses to the supermarkets contributes about 2 %.	Camilo et al., 2020
		The transportation of bananas, pineapples and melons represents more than 50 % of the impacts on fossil depletion, as calculated with a cradle-to-grave approach.	Frankowska et al., 2019
		For potatoes and tomatoes, transportation accounts for about 11–26 % in terms of GHG emissions with a cradle-to-grave approach.	Hu et al., 2019
		Transportation with packaging accounts for 66 % of the GHG emissions associated with tomatoes (including production, packaging and distribution in the study).	Pérez Neira et al., 2018
		Ship transportation accounts for 25 % of the impacts calculated with a cradle-to-grave approach and combining the impact categories results.	Wu et al., 2019
		The ocean freight of apples accounts for about 39 % of the carbon footprint calculated with a cradle-to-grave approach.	Iriarte et al., 2021
		Transportation within a palm oil plantation and labour transport accounts for 6 % (calculated with a cradle-to-gate approach concerning carbon footprint).	Munasinghe et al., 2019
		For tomatoes, transportation contributes 44 % of the impact on climate change due to the CO_2 emissions from trucks (calculated with the system boundaries including the processes from cultivation to distribution). The contribution to renewable energy use is 39 %, and terrestrial acidification is 50 %.	Payen et al., 2015
		Employee transportation is a major hotspot in terms of global warming potential and terrestrial acidification, contributing about 39 % of orchard gate global warming potential and about 46 % of terrestrial acidification (calculated with a cradle-to-gate perspective). The distribution phase contributed 92 % of the impacts on climate change when all supply chain stages were considered.	Sanderson et al., 2019
		Transport is the dominant activity, contributing 72–91 % (calculated with a cradle-to-gate approach).	Sim et al., 2007
		The production of tomatoes can represent 9–14 % of the total impact, while the production of apples can represent 6–12 % (including distribution beyond production) if delivery time is optimized or operating costs, respectively.	Bortolini et al., 2016
Processing	Production operations and activities related to preparation for sale are studied, considering environmental issues associated with water consumption (Subramaniam et al., 2020) and emissions generated from facilities (Bortolini et al., 2016).	The contributions regarding GHG emissions from the refinery subsystem of palm oil are as follows: boiler fuel 38 %, electricity 7 %, wastewater 18 %, spent bleaching earth 14 % and transport 23 %.	Choo et al., 2011
		For different fruits analysed regarding water footprint, processing accounts for 6–8 % or is negligible. But with reference to climate change, the drying process represents 45 % of the total impacts, calculated with a cradle-to-grave approach.	Frankowska et al., 2019
		For tomatoes, 14 % of GHG emissions were from processing (calculated including the phases of production, distribution and disposal).	Xue et al., 2021
		The juicing stage (pressing of fresh apples and bottling) contributes from 3 % (ecotoxicity and land use) to 69 % (water use) of total impacts, as calculated for apples with a cradle-to-grave perspective.	Le Féon et al., 2023
Temperature maintenance	Activities in the warehouses or during transportation are examined, focusing on food loss (Xue et al., 2021),	The transportation phase of fruits and vegetables accounts for 82 % of total emissions arising from cultivation to sale, considering only the cold chain. The carbon emissions of pre-cooling and storage and sales account for 7 % and 6 % of the total, respectively.	Bin et al., 2023
		In the case of PET packaging for strawberries (considering distribution), refrigerated transport represents about 39 % of the impacts (calculated as a single score combining human health, quality of ecosystem, climate change and resources). In the case of	Delahaye et al., 2023

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Table 3 (*continued*)

Aspects	Examples of how the aspects are addressed	LCIA relative contribution obtained in the studies analysed	Reference
		cardboard, refrigerated transport represents about 65 % of the impact.	
		The refrigerated warehouses, the first refrigerated transportation, and the retail stage represent more than 50 % of post-agriculture cold chain emissions.	Dong and Miller, 2021
		For different fruits analysed regarding primary energy demand, transport accounts for 17–64 % of the total impact (cradle-to-grave) due to distances and refrigeration. Only for strawberries and oranges, it accounts for 5–11 %.	Frankowska et al., 2019
Biowaste	Recovery activities and the disposal of the biowaste generated during the life cycle steps are studied (Frankowska et al., 2019; Parajuli et al., 2021).	The contribution of waste disposal is considerable for ecotoxicity categories.	Frankowska et al., 2019
		For tomatoes, 2 % of GHG emissions were from waste treatment (calculated including the phases of production, distribution and disposal).	Xue et al., 2021
Retailing	Operations during the sale activities, including considerations about building location, storage capacity, shelf-life, food volume, price, length of stay, shelf-life and sales, are analysed (e.g. Burek and Nutter, 2020).	In supermarkets, the main environmental impact is caused by refrigeration (60–70 %), followed by natural gas (5–10 %), interior and exterior lights (5–12 %) and equipment (3–8 %). Refrigerant loss accounts for 15 % of total GHG emissions. Similar considerations are obtained regarding non–renewable energy use and water scarcity.	Burek and Nutter, 2020
		For different fruits analysed regarding climate change, retailing accounts for 14–53 % of the total impact (cradle-to-grave). Some fruits have notable impacts in the retail stage, mostly due to the use of open display cabinets.	Frankowska et al., 2019
		Wholesale and retail stages account for up to about 38 % of the GHG emissions arising from cultivation to utilization.	Li et al., 2022
		Retailing consumption accounts for about 9 % of the carbon footprint calculated with a cradle-to-grave approach	Iriarte et al., 2021
		Retailing accounted for 1 % (ecotoxicity) to 19 % (ionizing radiation) of the total impacts (calculated for apples with a cradle-to-grave perspective).	Le Féon et al., 2023
Utilization	Maintenance of the products at home by consumers, cooking, or transportation towards sale centres is studied (Frankowska et al., 2019), discussing the reduction of food waste and the use of refrigeration technologies to prevent food spoilage (Dong and Miller, 2021).	The transport from retailing to the consumer's home accounts for about 9 % of the carbon footprint calculated with a cradle-to-grave approach.	Iriarte et al., 2021
		The consumption stage accounted for 1 % (land use) to 35 % (human toxicity) of total impacts due mainly to transporting the three products from stores to the consumers' households, mainly by automobile (calculated for apples with a cradle-to-grave perspective).	Le Féon et al., 2023

crops that can grow in greenhouse winter conditions (Rufí-Salís et al., 2020).

Regarding packaging, the use of active food packaging (e.g. antibacterial films), in some cases using films combined to have a lower environmental impact, can reduce the impacts associated with fresh products (Vigil et al., 2020). In addition, a balanced mix of reusable and single-use packaging can allow for lower impacts (Bortolini et al., 2018), along with a reduction of plastic (Delahaye et al., 2023). It is also useful to integrate studies on the maintenance of food quality as a result of packaging with environmental impact analysis, especially for temperature-controlled storage (Wu et al., 2019), in combination with distribution configurations materials, shapes and dimensions in primary and secondary packages, facility location issues, vehicle routing and delivery frequency (Accorsi et al., 2014).

Logistics, encompassing transport and distribution, plays a critical role in minimizing the environmental impacts associated with the food supply chain. Utilizing rail transport, as Caracciolo et al. (2018) suggested, can diminish the impacts of fuel consumption while maintaining reasonable shipping times. Additionally, employing more efficient transport methods and eliminating air transport, as noted by Sanderson et al. (2019); designing distribution networks with intermodal hubs (Bortolini et al., 2016); and using digital twins of refrigerated containers to monitor fruits and vegetable quality during transit (Lukasse et al., 2023) can further reduce environmental footprints.

The strategic localization of sites is essential for optimizing logistics. Improved management of decentralized logistics processing treatments across various locations, as Caracciolo et al. (2018) recommended, can lead to logistical efficiencies. By making distributions to smaller local food processing plants and adapting to seasonal flows, it is possible to diminish food waste. This reduction in travel distances not only aids shelf-life but also enhances food quality (Pedreschi et al., 2022). However, the solution to consuming locally available fruits, as proposed by Frankowska et al. (2019), requires a nuanced approach. While partially aligning with the findings of Loiseau et al. (2020) and Stone et al. (2021), a case-by-case examination is necessary. Sanderson et al. (2019) emphasized the importance of including distribution in environmental impact assessments of agricultural products, while Lukasse et al. (2023) suggested a synergy in data acquisition of different sensor systems and integrating the findings into one data ecosystem along the supply chain. In this context, Wu et al. (2019) advocated for integrating life cycle assessment with a virtual cold chain, enabling the identification and quantification of trade-offs between quality and environmental impacts. Regarding temperature maintenance, studies show that the long duration associated with temperature-controlled storage activities (storage/transport) represents an important opportunity for improvement (Burek and Nutter, 2020; Dong and Miller, 2021). As a result, reducing refrigerant releases and using efficient technologies can limit their effects (Dong and Miller, 2021). It is also useful to develop a data collection method that allows consumption and emissions associated with cold storage to be properly understood (Du Plessis et al., 2022).

One of the challenges associated with processing is about food loss during processing and production. This can be linked to biowaste management aspects (Dong and Miller, 2021) and can be addressed by integrating circularity concepts (Shabir et al., 2023), as well as enabling energy-efficient production in combination with a local supply chain (Pérez-Neira and Grollmus-Venegas, 2018). Additionally, other measures are the use of energy from renewable sources, which has been confirmed as one of the ways to reduce impacts on the environment (Hu et al., 2019), and the use of a controlled atmosphere to save energy and preserve food (Lukasse et al., 2023).

One of the solutions proposed by the studies to improve retailing is a reduction in the time spent by products inside supermarkets. This is because cold storage activities are sources of GHG emissions associated with energy consumption and refrigerant releases (Burek and Nutter, 2020). Reducing food storage and retail time, energy management in distribution centres and supermarkets and low GHG building designs are important measures to reduce the impact of food storage and retailing on the environment (Burek and Nutter, 2020).

The aforementioned are solutions to reduce impacts associated with utilization; thus, the habits of consumers regarding the reduction of energy consumption during storage and cooking (Frankowska et al., 2019) contribute to the optimization of consumers' food supply trips (Loiseau et al., 2020; Rasines et al., 2023). In addition, a diet structure change would play an important role in reducing the impacts (Xue et al., 2021), limiting the choice of non-seasonal products (Frankowska et al., 2019) and substituting the most impactful with other vegetables and

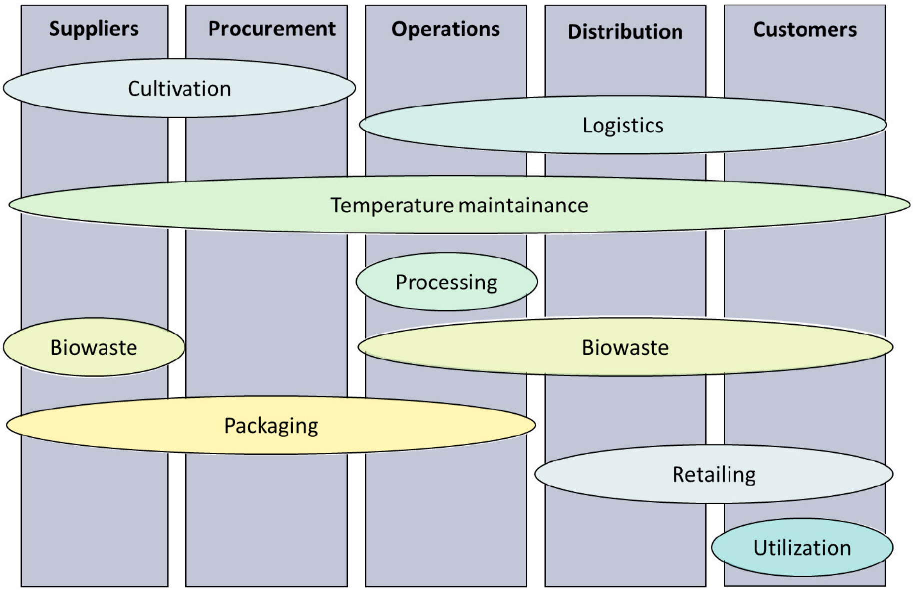


Fig. 3. Map of the aspects linked to the different actors/parties along the supply chain.

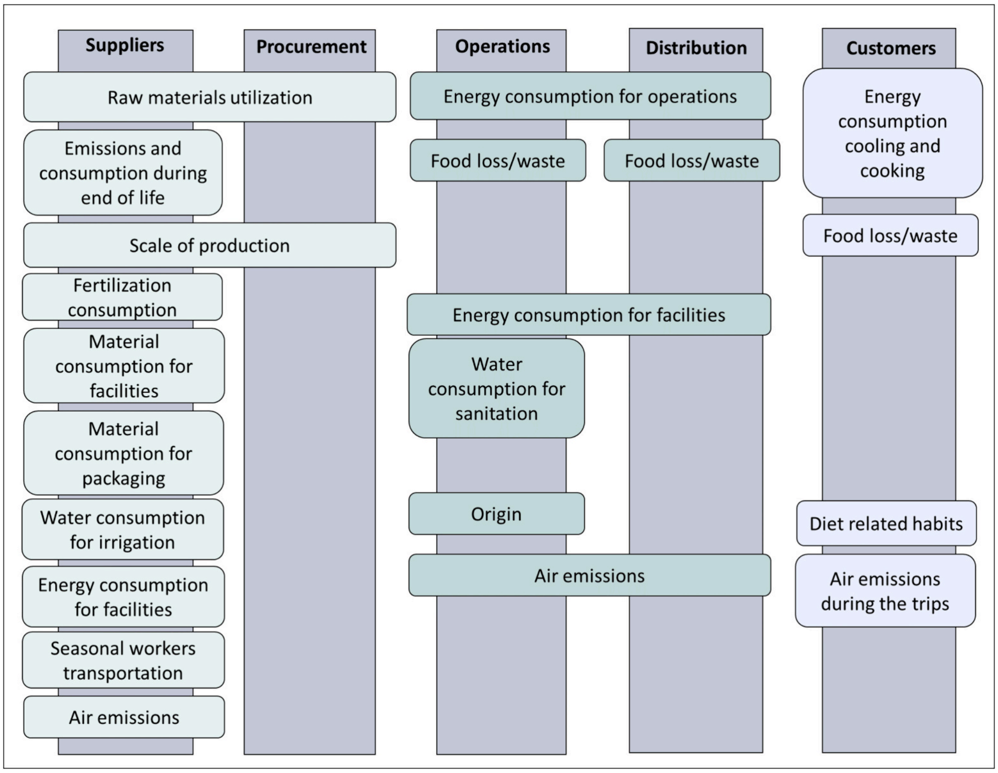


Fig. 4. Environmental concerns along the supply chain of fresh food from agricultural origin.

fruits (Xue et al., 2021). This would not be popular with the consumers, as the demand for certain fruits would be severely reduced due to climatic conditions and the perishability of some products (Frankowska et al., 2019).

The results obtained reveal the main aspects analysed by the LCA: studies of fresh food products from agricultural origin, highlighting the most studied life cycle phases, major contributions to the impacts on the environment and the solutions to reduce them. However, the identification of major impacts and contributions is influenced by the system boundaries applied in the different studies. As a result, some aspects may be important from a cradle-to-grave perspective but be less significant when the system boundaries include the use phase or the end-of-life phase. The solutions proposed in this research are concerned with the most explored aspects, i.e. materials for packaging, transportation and activities for temperature-controlled storage and cultivation, with less attention to the use phase and the generation of waste along the life cycle.

4.1.2. Implications at the Supply Chain Level

Going beyond the limits of the different studies, a cross-analysis of the articles studied shows that it is possible to outline a set of environmental concerns leading to improved actions that can be undertaken by different actors and organizations along the supply chain.

The results obtained, therefore, allow, starting from a map of the aspects linked to the different actors/organizations, to identify possible implications at the supply chain level. Fig. 5 represents the crossing of environmental improvement practices for each life cycle aspect, as found from the analysed studies, as well as the actors/organizations along the supply chain, leading to the following implications.

For suppliers and procurement (upstream level), it emerges that the consumption of resources, such as water and energy, is an important contributor to the environmental impact. It could be managed through the training of farmers and the use of plans to monitor and improve agricultural practices, including the reduction of inorganic fertilizers, biogas capture from anaerobic ponds, increase in the diversity of crop systems and, in some cases, the introduction of heating systems. Another important aspect is packaging, for which the use of innovative materials and volume optimization is beneficial, along with evaluations of packaging solutions in combination with distribution system configurations.

For production operations, energy consumption is an important contributor to the impact on the environment. In addition, waste and food loss generated during processing can be used to activate circular loops and designing a supply chain that is as local as possible. For logistics service providers, refrigerant gas releases, emissions and energy consumption are critical aspects that can be addressed through a systematization of the monitoring process, followed by data collection, optimization of the location of production and logistics sites, including intermodal hubs, and reducing the distances to improve the shelf-life management.

For the retailers (downstream level), it emerges that there are two main aspects. One is energy consumption, which can be reduced through building efficiency operations, and the other is food loss associated with expired products, which can be improved with better management of purchased stocks and reduction of product times in supermarkets.

For consumers (downstream level), the critical aspects are consumption and emissions associated with energy consumption, transport to the point of sale and household food waste. Optimizing consumption and food supply trips, along with reducing food waste, can reduce the impacts. A change in dietary structure also plays an important role in limiting the choice of non-seasonal products. This change not only aligns with environmental goals but also encourages consumers to become active participants in reducing the food supply chain's ecological footprint.

Through the product-focused approach, typical of the life cycle perspective, it was possible to reveal the environmental concerns of fresh food products from agricultural origin (Fig. 4) and the improvement practices which can be integrated into a fresh food products supply chain (Fig. 5), thus answering RQ1.

4.2. Intra- and Inter-Organizational View

The revealed practices range from individualized to highly interconnected approaches, from practices that can be put in place at the function and/or organization level to practices that can be applied only through cooperation with other parties along the supply chain, creating dyadic, triadic or extended network cooperation. Fig. 6 shows the practices represented in Fig. 5, classifying them as functional and organizational, thus representing an intra-organizational view, or as dyadic, triadic and extended practices representing an inter-organizational view (Carter et al., 2017). For instance, the reduction of inorganic fertilizer consumption with precision applications is associated with the upstream phase from a life cycle perspective but can also be seen as an intra-organizational practice, which can be put in place at a function level. Increasing the diversity of an agricultural system, combining different crops, capturing biogas, defining plans of improvement and training workers are also associated with the upstream phase from a life cycle perspective. However, they need cooperation at the organizational level and not just on a functional level to be applied. The importance of energy-efficient buildings and the use of efficient technologies are associated with the core phase of processing and the downstream phase of retailing from a life cycle perspective, but they can also be seen as intra-organizational practices, which can be put in place at the organization level. The integrated analysis of food quality maintenance and distribution configuration, which are linked to the upstream phase from a life cycle perspective, needs cooperation at the supply chain level to be realized, at least involving a dyad. The employment of intermodal hubs in the distribution network is linked to a downstream phase from a life cycle perspective but is also an inter-organizational practice that can only be realized with the cooperation of more actors, i.e. a triad. The integration of circularity emerging from the downstream phase from a life cycle point of view can also be seen as an inter-organizational practice that needs cooperation at the extended network level.

Even if the boundaries between intra- and inter-organizational practices in supply chain management can be blurry, with a gradual transition and varying degrees of involvement among supply chain actors (Carter et al., 2017), such boundaries become clearer. The life cycle perspective has allowed the display of a spectrum of practices interconnected with the different actors/parties along the supply chain from upstream (cultivation) to downstream (biowaste generation), thus answering RQ2. Fig. 6 shows these practices, assigning them to the different levels of cooperation along the supply chain.

It emerges that the practices identified through the life cycle–based approach display a spectrum ranging from individualized to highly interconnected approaches. This can be translated into three dimensions: technological, regarding the use of efficient and optimized technologies (e.g. Dong and Miller, 2021; Pérez Neira et al., 2018; Vigil et al., 2020); operational, regarding the reduction of raw materials consumption, distribution configurations and the improvements of crops (e.g. Caracciolo et al., 2018; Choo et al., 2011; Rufí-Salís et al., 2020); and management, regarding monitoring, improvement targets and local supply chain configurations (Accorsi et al., 2014; Frankowska et al., 2019; Lukasse et al., 2023). For instance, the precision application for fertilizers can be considered a technological improvement, along with active food packaging development, while the food storage time reduction at retailers can be seen as a management improvement, along with the training of workers and the development of a data collection system to monitor emissions and consumption. The employment of rail transport and increasing the diversity of the systems, combining different crops, can be seen as an operational improvement.

Practices linked to technological improvements predominantly fall within the intra-organizational domain. Examples include the utilization

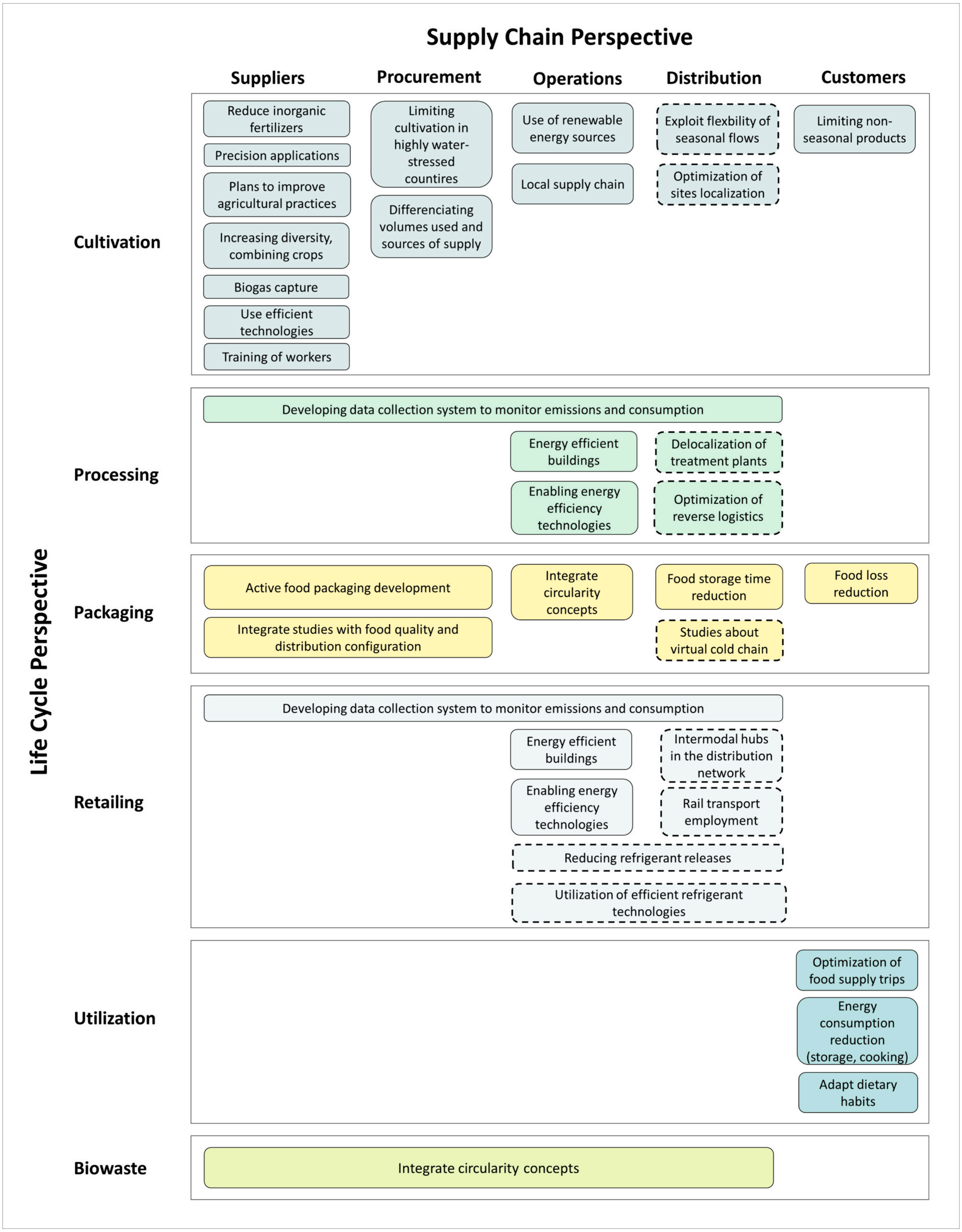
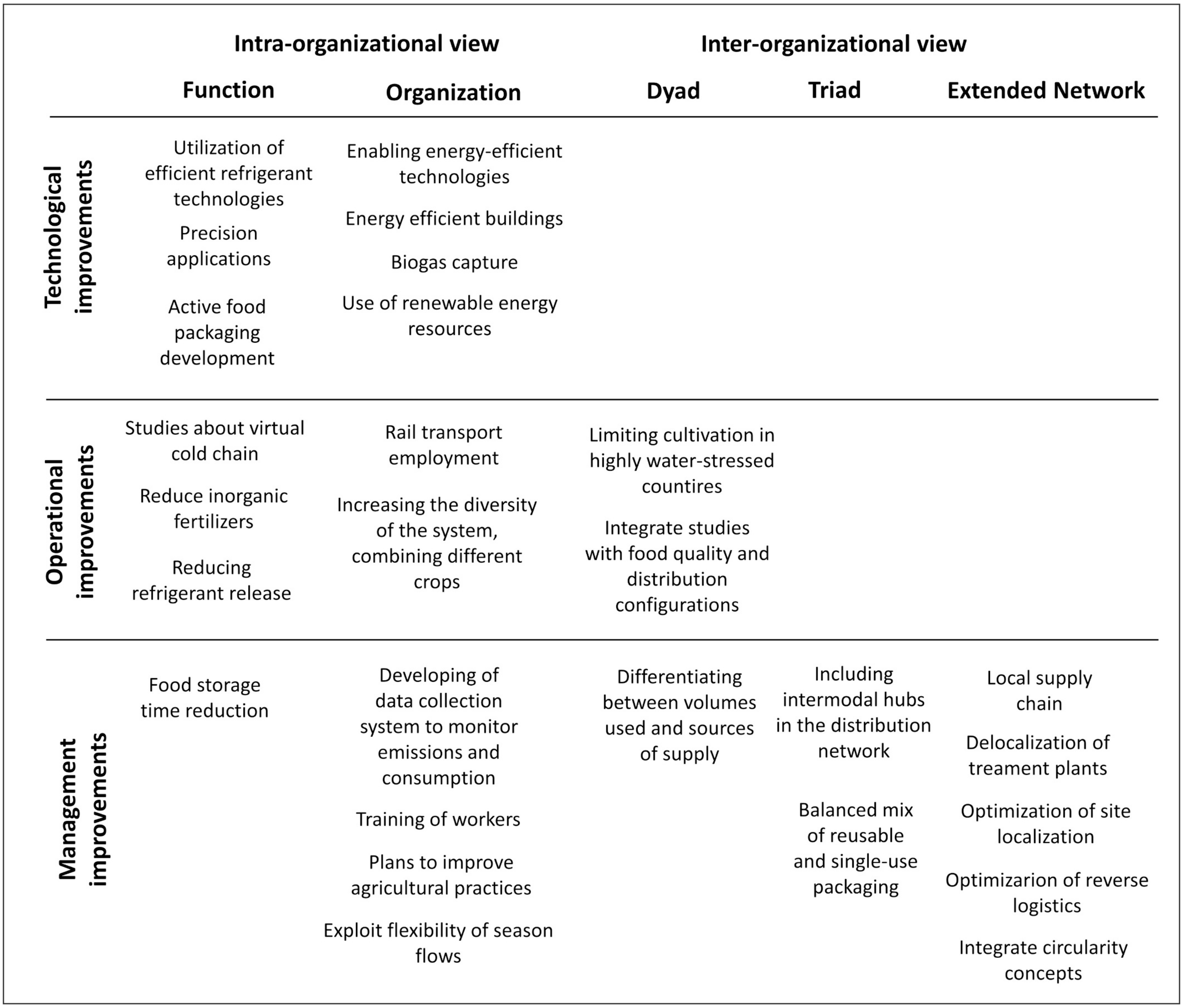


Fig. 5. Environmental improvement practices along the supply chain of fresh food from agricultural origin assigned to the different life cycle aspects.
Note: Logistics and temperature maintenance are represented with a dashed line, indicating that they are processes occurring among the different actors and the different life cycle–based aspects.

of efficient refrigerant technologies and precision application technologies to optimize the use of fertilizers. The practices linked to operational improvements, on the other hand, start from a business functional standpoint to an organizational view and inter-functional perspective, then gradually extend to encompass organizational and dyadic relationships. These practices involve refining day-to-day activities and procedures that directly affect the use of inorganic fertilizers and the employment of virtual cold chain applications. Such operational changes might include a combined analysis of food quality maintenance and distribution configuration to minimize waste and energy use.

Management practices encompassing the broadest spectrum aim to foster relational improvements that span from the intra-organizational level to the wider network within the supply chain. These practices involve developing and implementing strategies that not only improve internal management processes but also enhance collaboration and integration with other supply chain actors. Examples include adopting a local supply chain and delocalization of treatment plants. Ultimately, the integration of these practices (technological, operational and management) needs a more systematic and holistic approach to sustainable supply chain management (Wieland, 2021; Gómez and Lee, 2023). It allows for a deeper understanding of the various layers of interaction, from the internal workings of individual organizations to the complex link of relationships in the broader supply chain network. These practices mainly reflect an incremental approach trying to reduce the environmental impacts along the supply chain, which, however, may not be sufficient from a long-term perspective and should be included in a transformative approach (Gómez and Lee, 2023).

Crucial to future research is the exploration of short fresh food supply chains, particularly a comparison with their longer counterparts. This analysis should focus on identifying specific conditions under which short supply chains outperform traditional ones in terms of environmental impact, as highlighted by Loiseau et al. (2020) and Iriarte et al. (2021). Essential to this comparison is understanding how variables such as packaging, the scale of production and the distance between producers and consumers affect both the quality and safety of products (Pedreschi et al., 2022). Additionally, the debate should extend to the origin of fresh products and environmental impacts due to their transportation, exploring the nuances between local sourcing and distant sourcing, especially in varying climate conditions and with the use of heated greenhouses (Frankowska et al., 2019; Iriarte et al., 2021). Another significant area of inquiry involves the willingness of consumers to change their diet structures, examining the environmental



	Intra-organizational view		Inter-organizational view		
	Function	Organization	Dyad	Triad	Extended Network
Technological improvements	Utilization of efficient refrigerant technologies Precision applications Active food packaging development	Enabling energy-efficient technologies Energy efficient buildings Biogas capture Use of renewable energy resources			
Operational improvements	Studies about virtual cold chain Reduce inorganic fertilizers Reducing refrigerant release	Rail transport employment Increasing the diversity of the system, combining different crops	Limiting cultivation in highly water-stressed countires Integrate studies with food quality and distribution configurations		
Management improvements	Food storage time reduction	Developing of data collection system to monitor emissions and consumption Training of workers Plans to improve agricultural practices Exploit flexibility of season flows	Differentiating between volumes used and sources of supply	Including intermodal hubs in the distribution network Balanced mix of reusable and single-use packaging	Local supply chain Delocalization of treament plants Optimization of site localization Optimizarion of reverse logistics Integrate circularity concepts

Fig. 6. Improvement practices along the supply chain with an intra- and inter-organizational view based on Carter et al. (2017).

benefits and potential controversies of reducing non-seasonal product choices (Frankowska et al., 2019; Xue et al., 2021). These research directions are fundamental in unravelling the complexities of short versus long supply chains, aiming to optimize shorter chains for reduced environmental impact while maintaining or enhancing overall performance. Moreover, future research should delve into the potential of consumer education and awareness programs in reducing food waste. Further, it should explore how enhanced knowledge and mindfulness about the environmental impact of food choices can lead to more sustainable consumer behaviours and significantly contribute to waste reduction in the agri-food supply chain (Winkler et al., 2023).

Finally, for future research, there is an urgent need to address both economic efficiency and ecological sustainability. The concept of regenerative supply chains offers a transformative approach (Gualandris et al., 2024). Integrating this approach with life cycle–based methodologies can further strengthen its application. However, the implementation of these principles is not without challenges. By harmonizing the life cycle perspective with regenerative supply chain practices, future research can provide a more comprehensive understanding of the environmental, social and economic dimensions of sustainability, enabling more informed and effective decision-making. Thus, the background system of an LCA will be affected by the evolution of the socio-economic context and the introduction of new paradigms, e.g. the regenerative business (Hahn and Tampe, 2021), revealing the need of methodological advances, and possible integrations with prospective life cycle-based evaluations (Maes et al., 2023).

5. Conclusion

This research, through the analysis of 40 studies published by scientific journals, underscores the criticality of resource-intensive processes in the production, management and storage of fresh products, which are further complicated by their seasonality. The study categorizes and evaluates these studies based on various parameters, providing a comprehensive overview of the supply chain for fresh products, encompassing cultivation, processing, transportation, packaging, storage, waste management and consumer behaviour.

Key solutions identified for reducing environmental impacts include the advancement of packaging using active/antibacterial and low-impact materials, the adoption of low-emission transportation, the optimization of distribution networks, the enhancement of energy efficiency in distribution and retail centres and circular strategies in production. Particularly noteworthy is the potential environmental benefit of extending product shelf-life, which could significantly reduce food waste.

Nonetheless, the study acknowledges limitations, such as the potential exclusion of relevant articles not explicitly mentioning 'supply chain' but addressing the environmental impacts of fresh products. Moreover, environmental impact assessments are inherently relative and dependent on the defined boundaries of each study, which were different across studies. When the focus is on the environmental burdens of the packaging, the content is not included in the system boundaries; otherwise when the focus is the fresh food product a complete or a partial life cycle perspective is applied, i.e. from its cultivation to its disposal or from its cultivation to the point of sale or to the point at which it is consumed, thus addressing different combinations of life cycle phases. These are the reasons why further studies are needed to approach the life cycle thinking and the supply chain view from a systemic perspective, a connection often overlooked in current literature.

Despite these limitations, the review highlights critical aspects of the fresh product supply chain and identifies areas that need further exploration. Notably, while innovative packaging solutions have been extensively explored, there remains a gap in addressing consumer-related food loss. Future research could expand and apply the framework developed for this literature review to conduct further literature analysis on areas such as biowaste generation and food waste management along the supply chain.

The implications of these findings are significant for decarbonizing supply chains. By focusing on key areas, such as packaging innovation, transportation efficiency and waste reduction, there is a clear pathway towards more sustainable and less carbon-intensive supply chain practices. This research contributes to a deeper understanding of the environmental challenges in the agri-food sector and offers actionable insights for stakeholders aiming to mitigate these challenges and promote a more sustainable future.

CRediT authorship contribution statement

Sara Toniolo: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ivan Russo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Ilenia Bravo:** Writing – original draft, Investigation, Data curation.

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.

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