Sustainability implications of reverse logistics for perishable food products

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Abstract. Agri-food supply chains are multidimensional network-based systems, consisting of production, retailing and distribution processes, with sustainability aspects to be addressed, including transportation emissions and food loss and waste generation. The sustainability implications of food loss and waste recovery need to be analyzed in greater detail, along with the implications related to the returns of food product not respecting normative standards and commercial agreements. This research aims to analyze how sustainability is addressed along an agri-food supply chain in case of reverse logistics and to explore the main sustainability implications of reverse logistics for the suppliers of perishable food products. A two-fold approach is applied, a systematic literature review is elaborated, then a qualitative study is developed, exploring the reverse logistics activities for five companies producing perishable food products. From the results, it emerges that food loss and waste can be a significant burden with unnecessary use of natural resources, as well as the generation of additional climate-relevant emissions and costs. Scientific attention is directed to the prevention of losses and waste downstream in the supply chain, while upstream measures (from primary production to retail) remain scarce, although there is a large reduction potential at the production stage. Interventions to avoid product loss are still necessary to guarantee positive effects on sustainability on a global scale.

Keywords: Food loss and waste, Agri-food, Reverse Logistics, Sustainability, Perishable food products.

1 Introduction

Agri-food supply chains are multidimensional network-based systems, consisting of production, retailing and distribution processes, which depends upon long-distance transport in the import-export stage to facilitate product distribution [1].

According to Li et al. [2] transport is responsible for 19% of the total greenhouse gas emissions of the food supply chain. In addition, efforts to reduce food loss and waste (FWL) may increase these emissions as there is a risk that in order to valorize the food surplus and redistribute it through a circular system, there may be an even greater need for transportation in the repurposing phase. Food loss refers to the quantity of food that is lost in the production, harvesting, and processing phases, while the term food waste indicates food that is ready for human consumption but gets rejected during retailing, distribution or the consumption phases. The costs and benefits of food surplus recovery, endorsement and whether it justifies the required transportation expenses must be analyzed in greater detail to determine the feasibility. It is fundamental to assess and render quantifiable the implications of transportation in this supply chain, to avoid unnecessary expenses, reduce the overall impact on the environment, and to render the supply chain more sustainable [3].

In the last few decades, a great deal of importance has been placed on implementing more holistic approaches in supply chains that are economically, socially, and environmentally balanced. Research on reverse logistics (RL) is usually focused on the theoretical dimension, thus further studies based on empirical analyses conducted in real-life scenarios are fundamental to provide evidence of the impact of this approach [4].

Recycling and remanufacturing are seen as the principal RL processes that should render a supply chain more sustainable. Several studies have demonstrated that for companies to cope with the current competitive environment, RL could be utilized to gain a competitive advantage, increase revenues, and cut down on costs [5,6].

Despite the potential benefits of this approach, companies may face numerous barriers in the implementation of RL systems due to their major complexity, the necessity of skilled human resources, extra costs, and the element of uncertainty in achieving a successful outcome [7]. Another issue to consider is that if retailers exert excessive power over suppliers, the latter may be pressured into applying an RL approach [8]. Take-back agreements (TBAs), where retailers only pay for the number of products they manage to sell, are a form of RL. Retailers with greater bargaining power can adopt so-called “buy-and-burn strategies” where they over-purchase products that are unnecessary and subsequently send back the unsold items through returns of last-minute cancellations. The supplier is then forced to accept the returned goods that are more than likely to be nearing the expiration date. In these circumstances, they are forced to cover the transportation and reprocessing/disposal expenses of the returned items, which become an extra cost and loss for them [8].

Furthermore, the value of the returned products continues to fall the more time they are left unprocessed and even with remanufacturing only a fraction of the value could be regained. Additionally, the constant necessity of delivering products that are as fresh as possible, especially in the case of fruit and vegetables, place great pressure on the transport and logistics infrastructure [3].

As a matter of fact, the return of unsold products for free and market power imbalances are among the main factors responsible for generating FLW in the agri-food supply chain [8]. The main cause of FLW generation is the inefficient management of food surplus along the supply chain. From an economic perspective, decreasing FLW would be beneficial for all supply chain actors as more food products would be sold,

increasing profits and more food would be available at a reasonable price. From an environmental point of view, reducing FLW would decrease the consumption of natural resources employed in the production process, e.g. water, energy, soil, etc., exerting less pressure on the environment. Generating less FWL also has direct effects on society at large, in that there will be more food available extending food security to a wider population, e.g. through the redistribution of surplus food to the poor through food banks [9]. Additionally, another motivation for reducing the quantity of food wasted is incrementing awareness on the "food paradox" concept, i.e. the excessive amount of food being wasted while food security is not present worldwide [10].

In light of this background analysis, this research addressed the following research question:

RQ1: How is sustainability addressed along an agri-food supply chain in case of reverse logistics?

RQ2: What are the main sustainability implications of reverse logistics for the suppliers of perishable food products?

The main contributions of this study are revealing how sustainability issues related to reverse logistics along an agri-food supply chain are faced in the scientific literature, highlighting the main themes and methods of research and then revealing the main sustainability implications for the suppliers of perishable food products.

2 Methodology

This research is developed through a two-fold approach. RQ1 is addressed through a systematic literature review in line with the procedure proposed by Durach et al. [11]; while RQ2 is addressed employing a qualitative approach.

2.1 Systematic literature review

This review starts with an analysis of the studies that deal with the application of reverse logistics in the food sector, with a focus on sustainability. In line with the research questions, only studies regarding the reverse logistics of food products are included in this research. With the intent to include all the relevant studies, no temporal filters were applied (Table 1). The research was conducted in February 2025 through the ISI Web of Knowledge database with the following combination of keywords: "reverse logistics" AND food AND sustain*, leading to 105 results. After excluding proceedings papers and book chapters, 92 results were obtained, composing the baseline sample.

Successively, the baseline sample was used to identify the relevant studies focusing on the reverse logistics of food products and addressing sustainability. After analyzing title and abstract, 74 papers were excluded, leading to a final collection of 18 studies (Figure 1). With reference to the time of publication, the first article addressing this topic was published in 2017, and 2023 was the year with the greater number of papers (7 out of 18). In the first two months of 2025, 2 articles have already been published, a sign of an undiminished interest in the topic (Figure 2).

Examining the nationality of the first author of the papers shows that these are mostly located in Europe (8 cases, 3 of which are in Italy) and Asia (6 cases) territories where the agri-food sector is strategic for the economy.

The 18 selected studies were analyzed separately to reveal how the sustainability of reverse logistics is investigated for the food products, identifying the research methods employed, and the main themes.

Tab. 1. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Timeline	All the papers without a time filter	No exclusions
Document type	Articles published in journals	Conference proceeding chapters in a book, books
Language	English	Non-English
Subject area	Reverse logistics for food products	Direct logistics, food waste

Fig. 1. Systematic Literature Review Process

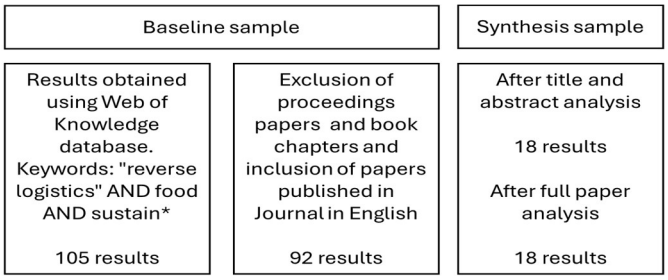
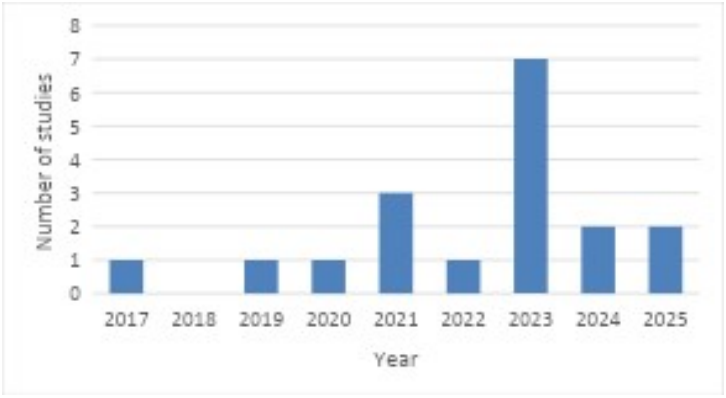


Fig. 2. Number of studies published per year.



2.2 Qualitative approach

A qualitative approach is applied with the intent of exploring the fates of the returns in the food sector and how they are managed, along with the packaging. Data were collected through semi-structured interviews maintaining a flexible style. The interviews were recorded and transcribed and lasted about 30 minutes. Experts were selected and a purposeful sampling was employed to include informants which can provide relevant information [12]. In line with Herzberg's study [13], five Italian companies of the agri-food sector were involved, all SMEs and suppliers of fresh food products, including fruits and vegetables, that distribute at a local and national level. Ten experts were involved based on their experience in the supply of fresh food products and management of returns from clients, as illustrated in Table 2.

The interview protocol included the following questions: i) How does the management of returns work? ii) What is the fate/how is each of these returns managed? iii) How are assets managed (i.e. pallets, other logistics packaging)? The results were coded through the methodology proposed by Gioia et al. [14].

Tab. 2. Role of the experts involved in this research

Case	N. of experts involved	Role in the company
Company 1	2	Chief Information Officer, Quality Manager
Company 2	2	Quality Manager, Sales Manager
Company 3	2	Chief Operations Officer, Administrative secretary
Company 4	2	Sales Manager, Chief Operations Officer
Company 5	2	Sales Manager, Quality Manager

3 Results

3.1 Reverse logistics sustainability along an agri-food supply chain

The studies selected for this research have investigated a variety of approaches and experiences that attempt to improve reverse logistics to create a more sustainable supply chain of agri-food products.

Many authors focused on analyzing the theme of reverse logistics from a theoretical perspective, providing a state of the art of this type of supply chain management and emphasizing the importance of reverse logistics and circular economy principles, using different analytical tools (topic mapping, co-citation, co-authorship and overlay visualization networks) [15,16].

Through LCA methodology it is possible to conduct an economic-environmental assessment of different reverse logistics scenarios, such as collecting packaged food waste, shipping it to a series of distribution centers for storage and to a treatment plant for reprocessing, with the goal of diverting waste from landfill disposal to alternative channels. In fact, several authors tried to assess the environmental impact of reverse logistics-related activities for specific agri-food products (i.e. bread, dairy, and meat), focusing their attention on packaged food waste in the supply chain, highlighting the

impacts of product transportation, take-back agreements, and the amount of waste generated in retail stores [3,17,18].

Various authors examined specific case studies, to present new models and frameworks with different goals in mind: to expand the scenario of closed-loop supply chain models; to demonstrate the importance of sustainable packaging in the context of food supply chain circularization; to transform waste generated as output by food service providers industry into co-products; to propose a set of sustainability performance indicators to assess circular economy practices [19-23].

In some cases, a multi-criteria approach (MCDM) was applied, proposing a hybrid approach using fuzzy TOPSIS (technique for order preference based on similarity to the ideal solution) and MSGP (multi-segment goal programming) to select an appropriate inverse logistics provider [24,25], and through the use of a fuzzy DEMATEL technique to obtain a comprehensive sustainability model that identifies the factors necessary to quantify the interrelationships [26]. Different mathematical models were developed also for costs and carbon dioxide emissions quantification, reproducing the main food cold supply chain processes (product collection, backroom storage, product delivery and reverse logistics) in order to estimate and predict the economic and environmental impacts of a RL in a food supply chain [27,28]. Kazancoglu et al. [29] aimed to minimize/eliminate risks that arise during the process of implementing reverse logistics activities, with process-integrated Blockchain technology, in sustainable food supply chains. The risk assessment was carried out based on the opinion of experts in the field, investigated through a questionnaire.

A further approach is represented by the Delphi-based analysis in the construction of a framework for decision-making on the sustainable orientation of business practices, which aimed to examine the future role of reverse logistics as a sustainability tool in food supply chains [30]. Themes and research methods to address reverse logistics sustainability along an agri-food supply chain, as addressed in the selected studies, are illustrate in Table 3, giving an answer to RQ1.

Table 3. Unit of analysis and methodologies used in the studies examined.

	Authors (year)	Themes	Research methods
1	Attia (2025)	Food industry enterprises in the UAE	Online survey
2	Barbosa (2021)	Supply chain management (SCM) practices	Literature review
3	Bottani et al. (2019)	Packaged food waste in the supply chain, focussing on the amount of waste generated in retail stores	Life Cycle Assessment
4	Bottani et al. (2022)	Food cold supply chain	Mathematical modelling for costs quantification

5	Esmaeilbeigi et al. (2021)	Dairy industry, a value-creating whey recovery network	Mathematical modelling with average approximation method and accelerated Benders decomposition algorithm
6	Kazancoglu et al. (2021)	Flows in reverse logistics	System Dynamics Model with case study application
7	Kazancoglu et al. (2023)	Benefits and risks of blockchain technology adaptation in SFSCs	Fuzzy Synthetic Evaluation, survey
8	Kumar et al. (2023)	Circular economy adoption challenges in Indian FSC	Two-phase multicriteria decision making (MCDM) based research methodology, interpretative structural modeling (ISM), integrated grey DEMATEL technique
9	Lagarda-Leyva et al. (2023)	Waste management in the food service provider sector	Seven-step procedure originating from merging of reverse logistics and system dynamics principles
10	Münch et al. (2023)	Reverse logistics in food sector	Delphi-based scenario analysis, quantitative and qualitative data analysis, dissent and sentiment analysis, fuzzy c-means clustering
11	Sgarbossa and Russo (2017)	Closed-loop supply chain	Qualitative approach (with field data and interviews)
12	Shahidzade and Shokouhyar (2023)	Proposition of a closed-loop sustainability development model	Linguistic interval-value hesitant fuzzy (LIVHF) DEMATEL, literature review, factor identification, sensitivity analysis
13	Sundgren (2020)	Different emerging SC structures	Qualitative approach (interviews and observations)
14	Veloso et al. (2025)	Indicators for the agri-food sector	Qualitative approach (focus groups and interviews)
15	Wang and Liao (2023)	Reverse logistics providers	Hybrid approach using fuzzy TOPSIS (technique for order preference by similarity to ideal solution) and MSGP (multi-segment goal programming) methods, case study methodology, Multi-Criteria Decision Analysis, Multi-Segment Goal Programming, Multiple Objective Decision Making, Delphi techniques
16	Weber et al. (2023)	Bread leaving the bakery gate	Life Cycle Assessment
17	Zambujal-Oliveira et al (2024)	Sustainable product-package designs	Multi-Criteria approach (MCDM) with literature case analysis
18	Zarreh et al. (2024)	Perishables products utilization into Closed-Loop Supply Chains	Literature review

3.2 Reverse logistics sustainability for perishable food products

The answers given by the respondents involved in this research revealed the importance of the perishability of the product being marketed, whose demand is influenced by freshness and consumption and linked to safety and quality standards. According to 4 out of 5 respondents, factors that contribute to the maintenance of these standards are related to the mode of transport, location of outlets, and distribution centres.

One of the key themes that emerged during the interviews was that of sustainability. It emerged from the interviews that while it is easier to manage sustainability in social terms, through codes of ethics and labour discipline, it is not so easy from an economic and environmental point of view. All interviewees agreed that returns create a second line of transport by road, with different methods and timing, which can have an impact on both product quality and the environment. In particular, one respondent states that the management of the expiry date, as well as the collection and processing of waste products, are responsible for the greatest impacts, both environmental and economic.

From an economic perspective, returns represent a significant cost for the company and the producer, as there is an investment of resources related to all reverse logistics and above all a lost direct source of income. In addition, these processes generate negative environmental impacts, as the fate of these returns, especially if deemed non-compliant with legal regulations, must be landfilled, resulting in loss of product, direct income, and an increase in disposal costs.

Even if the products deemed suitable were offered to one or more secondary markets (local markets, other exchange platforms, donation, etc.), the costs would still be attributed to production and supply, including the new packaging materials and processes applied.

With regard to packaging systems, the manager of one of the companies states that sustainable alternatives that generate a smaller impact do exist but are still impractical and have high costs; they also state that the company prefers to promote an optimised recycling process of plastics.

From the collection of all the various statements, the complementarity of the entire supply chain is emphasised, as it is composed of production, distribution, and retailing centres; only through strategic planning of distribution and logistics can sustainability goals be achieved.

Therefore, in their opinion, it is important to maximise profitability, minimise production costs, and increase the level of customer satisfaction.

Among the most frequently used keywords in the interviews there were ‘planning and coordination’, ‘investment and technology’, ‘standards and requirements’, ‘fiscal incentives and contractual conditions’, and ‘knowledge and awareness’.

4 Discussion

The present study showed that devoting resources to both sustainable supply chain management and reverse logistics leads to more effective sustainable reverse logistics practices.

Based on the statements of the interviewees, three thematic areas have been identified and categorized into three levels (1st order concepts, 2nd order themes, aggregate dimension), as illustrated in Figure 3 and giving an answer to RQ2.

The first dimension is competitiveness, the ability to adapt and respond to changes in the market. To remain competitive, companies predict production quantity and prepare for production by planning based on records of previous years. This is done to guarantee clients a supply of quality products throughout the year. One of the obstacles is the presence of different commercial channels, e.g. large scale distribution, general markets, packagers, the fourth and fifth range industry. For this reason, prices, quantities, and products returned vary based on the channel they come from. According to the interviewees, a possible solution could be to improve the communication between producers, buyers, and retailers.

A good level of communication also has repercussions on consumers as transparency and traceability of production are guaranteed. One of the actors interviewed stated that the return quantity can be associated with the satisfaction of the client, i.e. if no products are returned then it can be deduced that the client is satisfied. However, in certain cases, the cause of returns is associated with aesthetics issues. Despite the quality assessment, following stringent protocols, being carried out by both the producer and the point of sale, returns still occur due to products not coinciding with the standards of the consumers.

Moreso, from the interviews it emerges that some pretentious situations may also occur, that is, it can happen that the conforming goods are returned for other unclear reasons, e.g. an anomaly in the packaging or a transport pallet that is too high (strategic returns). These controversies lead to sanctions and economic losses for producers, who see their products devalued.

As for the fate of these returns, interviewees said that usually the producer evaluates whether the quantity to be collected is convenient compared to the cost and time of collection of the goods. Very often there is no economic convenience in accepting returns and reallocating the products elsewhere. If the collection option is chosen, the product is returned and, if in good time, it is reconditioned, reprocessed, and sent to another market. In some cases, however, large-scale distribution is authorized to donate it to charity, the costs of which fall on the producers. Deformed or broken products can also be marketed in the catering sector or donated to employees, food banks, or other recipients. A possible solution proposed by most of the interviewees is to initiate the optimization of supply chain processes through investments in materials and advanced technologies.

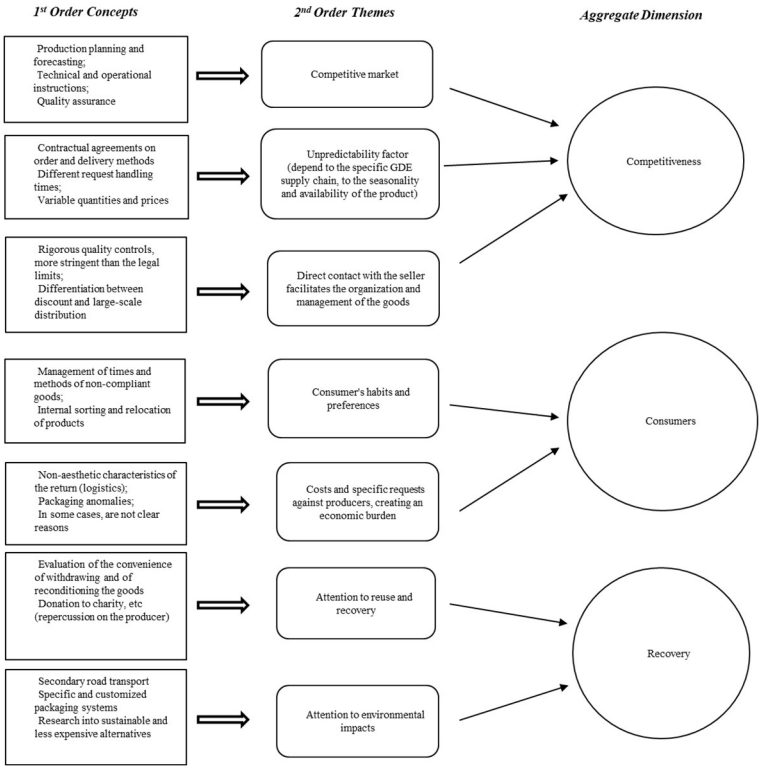


Fig. 3. Concepts and themes revealed through this research

5 Conclusion

The aim of this study was to reveal the sustainability implications of reverse logistics for perishable food products. The results reflect the subjective views of actors regarding returns and the question of what can and should be done to reduce this phenomenon.
From the results, it emerges that food loss and waste can be a significant burden with unnecessary use of natural resources, as well as the generation of additional climate-relevant emissions and costs.
Policies are key to guide choices towards food loss and waste reduction by all actors along the food supply chain, as proposed by the SDG (12.3). Scientific attention is directed to the prevention of losses and waste downstream in the supply chain, while upstream measures (from primary production to retail) remain scarce, although there is a large reduction potential at the production stage. Interventions to avoid product loss are still necessary to guarantee positive effects on food security and environmental sustainability on a global scale.
The study is limited in that the number of producers interviewed is not representative of the entire Italian scenario. Therefore, further studies and considerations are necessary to amplify the research and cover other aspects.

The highlights of this study regard the perspectives of supply chain actors on food loss and waste prevention policies that are often overlooked. The combination of a theoretical framework and a practical approach is fundamental to highlight the importance of these issues.

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