CIRCULAR ECONOMY AND FOOD WASTE IN SUPPLY CHAINS: A LITERATURE REVIEW

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Abstract

This paper aims to analyse how circular economy (CE) is implemented in the context of food supply chains (SCs) and understand how supply chain management (SCM) can support the transition towards a CE of food waste (FW). Based on a Systematic Literature Review (SLR) and Citation Network Analysis (CNA) of 333 papers, the focus of the study is located at the intersection of three areas, i.e. FW, CE and SCM. We explored how these concepts and fields of research relate to each other and identified research trajectories. The analysis and the synthesis of the reviewed papers allow for identifying research areas and highlighting a lack of a holistic discussion of FW, CE and SCM, which appear weakly related to each other in the existing literature, even if they are essential to the development of circular SCs in the food industry. A research agenda is drawn to drive future research endeavours.

Keywords

Food waste; Circular economy; Supply chain management; Food supply chain; Citation Network Analysis; Systematic Literature Review

1. Introduction

The Food and Agriculture Organization of the United Nations estimated that around one-third of the food produced worldwide goes to waste, generating negative impacts at environmental, social, and economic levels (Food and Agriculture Organization (FAO), 2019). The magnitude and relevance of this issue is reflected by its inclusion in the 2030 Agenda for Sustainable Development, developed by the United Nations in 2015, namely in target 12.3, which states: *By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses* (United Nations, 2015; Food and Agriculture Organization (FAO), 2019). The importance of tackling the problem of FW is evident when the impacts of sustainability associated with the phenomenon are considered. At the environmental level, the food produced but not consumed represents a waste of resources, mainly water, energy, and land, and is also associated with the emission of greenhouse gases, which contribute to global warming and climate change. It has been estimated that food loss and waste accounts for 8% of the overall amount of global greenhouse gas emissions (Vilariño, Franco and Quarrington, 2017). As for the social implications of FW, it reduces food security and availability; consequently, lowering FW could reduce world hunger. Also, waste is inevitably associated with a price increase due to limited supply. This highlights the fact that FW also has negative implications at the economic level since it can limit the profitability of a company, affect the cost of operations, and, as previously mentioned, increase the cost of food (Vilariño, Franco and Quarrington, 2017; A Bhattacharya and Fayezi, 2021).

The complex scenario created by a generation of significant amounts of FW requires a systemic and holistic approach to its resolution (Do *et al.*, 2021). Scholars and practitioners widely recognized the potential of applying CE concepts to manage and reduce FW, even if the complexity is high, since food products are automatically downgraded at each cascading loop (Ellen MacArthur Foundation, 2013, 2019; Halloran *et al.*, 2014). With its report published in 2012, the Ellen MacArthur Foundation defines the concept of CE as "*an industrial system that is restorative or regenerative by intention and design*" and is opposed to the standard linear model "take-make-dispose"." The central idea underlying CE is closing the materials' loop by replacing the end-of-life with alternative solutions. CE principles support the development of this new vision of the economy, where the reconceptualization of waste as a resource can be a trigger for disruptive innovation (Ellen MacArthur Foundation, 2012). The ability to see where the generated waste might become a resource can facilitate this vision-shift (Perey *et al.*, 2018).

The switch to a CE requires radical transformations, and for companies, this translates into the need for strong commitment, strategic decisions, and overall cultural and organizational changes (Maranesi and De Giovanni, 2020). Tackling such significant changes can be challenging for a single company: a positive correlation has been shown between the level of integration and collaboration in the SC and the number of CE objectives collectively pursued (Elia, Gnoni and Tornese, 2020). In fact, poor SCM and poor design of logistics networks can be a cause of FW (Balaji and Arshinder, 2016; de Moraes *et al.*, 2020; Magalhães *et al.*, 2021). This can lead to hold-ups in logistics and SC aging, where products spend most of their shelf lives in the SC instead of in retails or consumers' pantries (Göbel *et al.*, 2015; Akkas, Gaur and Simchi-Levi, 2019). A lack of collaboration, communication, and information sharing (also in terms of traceability), and a lack of an integrated IT system along the SC can exacerbate the inefficiencies in logistics (Balaji and Arshinder, 2016; Vats, Gupta and Sharma, 2019; de Moraes *et al.*, 2020; Despoudi, 2021).

This SLR aims to analyze how CE is implemented in the context of food SCs and understand how SCM and logistics can support the transition towards a CE of FW. The following review question has guided the development of the present SLR: *How can supply chain management and logistics support the development of circular economy in food supply chains for the reduction or valorization of food waste?*. This approach locates the field of study at the intersection of CE, SCM and logistics, and FW, which represent the key research areas of this work. The SC perspective of the present research focuses on the value-adding activities of the chain, from agriculture to retail, excluding the consumption stage. This choice has been made because the generation of FW during consumption requires a specific investigation of consumer behavior, ethical consumption, and related implications (Stancu, Haugaard and Lähteenmäki, 2016). Restricting the scope of the analysis to the upstream tiers of the chain has allowed for an in-depth analysis of the FW and CE phenomenon in this portion of the food SC. A further specification is needed for the adopted terminology since there are many definitions related to FW. While acknowledging the differences between the various concepts regarding food waste, and in order to avoid confusion when discussing the several papers retrieved from literature, in this document the term FW will encompass all food waste, losses, byproducts, scraps, and surplus generated at any stage of the food SC, whether it be edible or not (Chaboud and Daviron, 2017).

The current study can help rationalize the wide body of literature available on the theme of FW, and the adopted SC perspective provides insights on the understudied topic of the operationalization of CE in food SCs. Some propositions will be laid out so as to frame the currently studied topics and highlight the existing research gaps, which can be filled with further research. Practitioners can also benefit from this work, for it can help in understanding the context of FW, CE and SCs, and it also highlights the leverage points to develop innovative and more effective approaches for the reduction of FW along SCs.

2. Materials and Methods

The chosen research methodology is the SLR, which adopts a replicable and transparent process to locate, select, and evaluate existing studies (Denyer, D., & Tranfield, 2009). Starting from the review question, a set of keywords was identified for each of the investigated research areas (see table 1) in order to embed the scope of the research into the literature review.

Table 1 - Keywords for each research area

RESEARCH AREA	KEYWORDS
FW	“food waste” “food scrap*” “food surplus” “food byproduct*” “food loss*”
CE	“circular economy”
SCM, Logistics	“supply chain*” “supply network*” “supply chain management” “logistic*”

Regarding FW, this selection of keywords was dictated by the need to include all the possible flows of materials leaving the food SC. The chosen words are often used as synonymous (Chaboud and Daviron, 2017), but they each have slightly different meanings that describe various reasons why food, or a part of it, doesn’t reach the end consumer.

The choice to use only the keyword “circular economy” for this field is related to the decision to consider the officially recognized definition of CE proposed by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2012). This decision implied the exclusion from the keywords of similar concepts, such as the 3Rs (reuse, reduce, recycle), or other similar frameworks (e.g., 9Rs, industrial symbiosis, etc.).

The keywords about SCM and logistics were chosen to give an SC perspective to the research, so “supply chain” and its synonymous “supply network” have been included.

The following three research strings were generated using Boolean operators:

1. *((“circular economy”) AND ("supply chain*" OR "supply network*" OR "logistic*" OR "supply chain management"))*
   This search isn’t specifically about the food industry and aims at highlighting how other markets and SCs are dealing with CE to give an overview on the current situation and provide a base for comparison;
2. *(("food waste" OR "food scrap*" OR "food surplus" OR "food by-product*" OR "food loss*") AND ("supply chain*" OR "supply network*" OR "logistic*" OR "supply chain management"))*
   This second query is focused on FW and how it is managed along the SC, with a broader view that also includes logistics and SCM practices;
3. *(("food waste" OR "food scrap*" OR "food surplus" OR "food by-product*" OR "food loss*") AND ("circular economy"))*
   The third combination is explicitly about CE practices involving FW and other possible sources of waste in a food SC (*i.e.*, by-products, scraps, losses, and surplus).

The combined analysis of the outcomes of these three search strings allows for investigating the intersection among the three research areas. The searches were conducted using the Scopus database and adopting some inclusion criteria (figure 1). The restriction about the publication year (the articles had to be published from 2012 onwards) was adopted because the officially recognized definition of CE was given by the Ellen MacArthur Foundation in that year (Ellen MacArthur Foundation, 2012). Before starting the screening of the articles, duplicates were removed. Some exclusion criteria was applied and is detailed in figure 1. In line with the scope of the research, which focuses on companies operating in the food SC from an industrial perspective, those papers dealing only with FW generation at the consumption level were excluded from the analysis due to different dynamics present at the consumer level (Stancu, Haugaard and Lähteenmäki, 2016). Once the sample was defined with full-text reading, some other publications were retrieved by means of forward and backward referencing. The selected papers include both peer-reviewed articles and contributions belonging to grey literature. The latter were included since they are highly cited and bring important contributions to the research fields of FW (mainly FAO publications) and CE (e.g., reports developed by the Ellen MacArthur Foundation). The above-described steps led to a final sample of 333 selected papers.

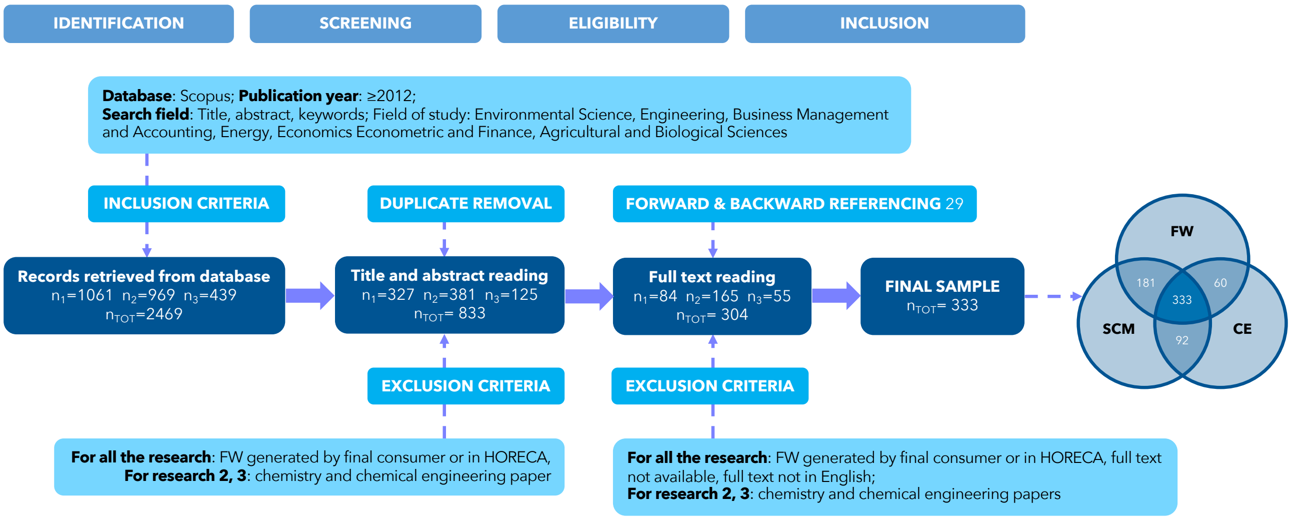

Figure 1 – PRISM diagram of the SLR, with inclusion and exclusion criteria

The sample of selected papers has been analysed quantitatively, with descriptive analysis and a CNA, and qualitatively through a content analysis. These different approaches allow for the examination of the paper sample from multiple perspectives to obtain independent and complementary insights that can enrich the literature analysis. Given the broadness of the current paper sample, the availability of distinct points of view can give robustness to the analysis of literature, since it provides diverse sources of evidence that support the discussion. As will be thoroughly explained in the following sections, the CNA offers an overview of the structure of the field under investigation, unveiling connections among papers and research topics and trajectories in order to study the process of knowledge creation and development (Colicchia and Strozzi, 2012). The content analysis, on the other hand, allows for delving deeper into the subject matter of the various reviewed contributions to first analyse and then synthetize the paper sample (Denyer, D., & Tranfield, 2009), with the aim of going beyond CNA that maps the field under investigation and only considers citations (Colicchia and Strozzi, 2012).

3. Results

3.1 Descriptive Analysis

Descriptive statistics were used to initially analyse the paper sample. Exploring the most cited papers in the sample can give a picture of the "seminal articles", listed in table 2, that are highly relevant to this research field. One of the most important papers was by Papargyropoulou *et al.* (2014), wherein the food waste hierarchy (FWH) is presented. Looking at the other most cited papers, a recurring theme is the identification of valorization and prevention options for FW. The topic of CE emerges explicitly in one document only, as well as the role of consumers in the acceptance of circular products.

Table 2 – Top 10 ranked papers for number of citations in the sample

Rank	Title	Author	Year	Citations
1	The food waste hierarchy as a framework for the management of food surplus and food waste	Papargyropoulou *et al.*	2014	572
2	Current options for the valorization of food manufacturing waste: A review	Mirabella, Castellani and Sala	2014	504

3	A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective	Govindan and Hasanagic	2018	268
4	Transition towards circular economy in the food system	Jurgilevich *et al.*	2016	205
5	Fish processing wastes as a potential source of proteins, amino acids and oils: A critical review	Ghaly *et al.*	2013	193
6	Food waste prevention in Europe - A cause-driven approach to identify the most relevant leverage points for action	Priefer, Jörissen and Bräutigam	2016	176
7	Addressing food waste reduction in Denmark	Halloran *et al.*	2014	167
8	Recycling, recovering and preventing "food waste": Competing solutions for food systems sustainability in the United States and France	Mourad	2016	164
9	Opening the black box of food waste reduction	Garrone, Melacini and Perego	2014	162
10	Consumer product knowledge and intention to purchase remanufactured products	Wang and Hazen	2016	150

A different perspective on highly cited articles can be had by considering the citations per year for each paper, calculated by dividing the total citations by the number of years since publication. This approach allows for better comparing recently published articles with older ones, highlighting the “breakthrough papers” that have gained recognition in the scientific community, even for a short period of time (see table 4). Some of the documents are also highly cited in absolute terms, but the other contributions treat CE more extensively and from different perspectives, or discuss innovative technologies, such as blockchain and industry 4.0. One article that has gained a great amount of attention is the one by Nandi *et al.* (2021), which discusses the impact of COVID-19 on the conceptualization of SCs for CE.

Table 3 – Top 10 ranked papers for number of normalized citations in the sample

Rank	**Title**	**Authors**	**Year**	**Years since publication**	**Citations per year**
1	A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case	Gunjan Yadav *et al.*	2020	1	104
2	A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective	Govindan and Hasanagic	2018	3	89.3
3	The food waste hierarchy as a framework for the management of food surplus and food waste	E. Papargyropoulou *et al.*	2014	7	81.7
4	Current options for the valorization of food manufacturing waste: A review	Mirabella, Castellani and Sala	2014	7	72
5	Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste	Teigiserova, Hamelin and Thomsen	2020	1	61

	hierarchy, and role in the circular economy				
6	Strategy development in the framework of waste management	Zorpas	2020	1	58
7	Redesigning Supply Chains using Blockchain-Enabled Circular Economy and COVID-19 Experiences	Nandi *et al.*	2021	1	57
8	Circular economy transition in Italy. Achievements, perspectives and constraints	Ghisellini and Ulgiati	2020	1	55
9	Value-added chemicals from food supply chain wastes: State-of-the-art review and future prospects	Xiong *et al.*	2019	2	53.5
10	Sustainable consumption in the circular economy. An analysis of consumers' purchase intentions for waste-to-value food	S. Coderoni and Perito	2020	1	53

3.2 Citation Network Analysis

To further study the retrieved sample of papers, an analysis of the citation network was carried out using the software VOSviewer (version 1.6.17). CNA graphically represents the research field, allowing for visualizing the citation structure of the sample and for studying the connections among papers. Each node represents a paper, and its size reflects the number of received citations; the links between nodes show citations between papers, and it is assumed to illustrate how works have been influenced by previous researches (Zhao and Strotmann, 2015). The network could include isolated nodes, representing articles that are not linked to other publications through citations; these disconnected nodes are not considered to be part of the main connected component of the network.

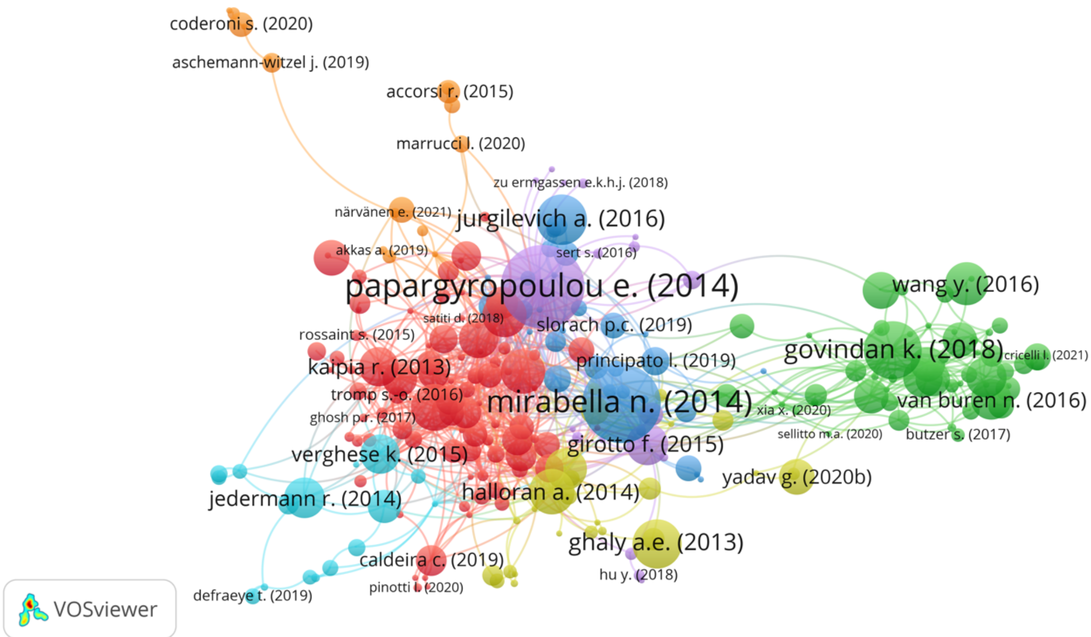

Figure 2 – Citation network of the paper sample, connected component (obtained with VOSViewer 1.6.17)

The study was conducted on the whole paper sample, but for some papers it was not possible to retrieve the citation data, thus the number of articles composing the analyzed sample is 315. In this sample, the connected component is made up of 258 nodes, with a total of 788 links; the resulting citation network is displayed in figure 2.

Looking at the citation network, a particular structure can be identified, with the connected component divided into two distinct groups of nodes. Analyzing the articles in each group of nodes, it becomes clear that the set of nodes on the right-hand side of the chart deals mainly with logistics, SCM, and CE. The group of nodes on the left-hand side includes papers that explicitly discuss FW, either related to CE or with SCM and logistics. The sets of nodes are related with some links, meaning a connection between these topics had been previously established in the literature through citations, even if not extensively.

VOSviewer allows for dividing the citation network into clusters, which represent groups of papers discussing similar themes. This view can give insights on the most debated research areas, allowing for visualizing the general structure of the literature on the investigated topic before providing a detailed description of the papers through the content analysis.

From the application of the VOSviewer clustering algorithm (van Eck and Waltman, 2017) seven clusters of papers were identified, as highlighted in figure 3.

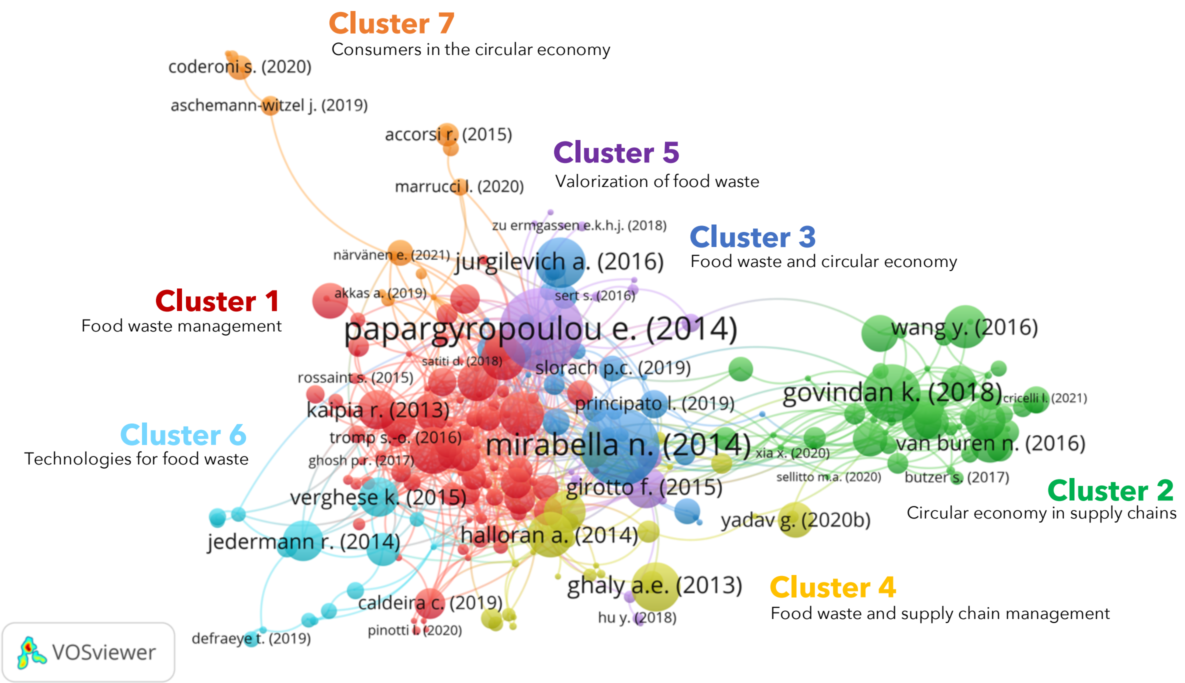

Figure 3 – Clusters of the citation network, connected component (obtained with VOSViewer 1.6.17)

Cluster 1 - "Food waste causes, solutions, and measurement" encompasses papers that discuss the issue of FW in terms of causes, quantification and measurement methods, and available solutions. The cluster has an overarching perspective on the theme of FW, since it discusses how it originates and potential remedies that can be implemented by organizations. Measuring the generated waste is key to assess the magnitude of the problem, the nature of the waste, and consequently identify the most suitable solutions.

Cluster 2 - "Circular economy in supply chains" includes all the articles in the set of nodes on the right-hand side of the network. It explicitly treats CE in SCs, both in developed and developing countries, regarding barriers and drivers for implementation, SC models and configuration, performance measurement, and governance.

Cluster 3 - "Food waste and circular economy" discusses the topic of FW specifically in relation to CE by including articles that describe available solutions to manage and valorize FW according to a CE perspective, decision-making models, and performance measurement frameworks: the latter are frequently associated with the use of the life cycle assessment methodology.

Cluster 4 - "Food waste and supply chain management" contains articles that describe FW and its management or prevention from an SC perspective, considering the role of collaboration between SC actors, the importance of the logistics functions, and SC configurations with their management.

Cluster 5 - "Valorization of food waste" groups a set of papers that discuss different practices to valorize FW, according to the FWH. Much attention is devoted to anaerobic digestion, production of biogas and other biofuels, the extraction of bioactive compounds, and production of bioplastics. Other articles also discussed the utilization of FW for animal feed production or its redistribution for human consumption.

Cluster 6 - "Technologies for food waste" comprises papers discussing different technologies that can be employed to prevent FW. Some of the cited available options are Internet of Things (IoT) sensors, improved and intelligent packaging, digital twins, temperature monitoring, and mathematical models for quality decay; these solutions are mainly applied to the cold chain.

Cluster 7 - "Consumers in the circular economy" mainly discusses issues related to the SC interface with consumers. One aspect present in this cluster is the analysis of FW in retail stores, which are in direct contact with consumers. Another relevant topic is the consumers' acceptance of circular food products, i.e., food products obtained from the upcycling of FW.

Observing the themes emerging from the cluster analysis, FW appears as a pivotal point, which is more generally discussed in the biggest cluster, *i.e.*, cluster 1, and then examined in different ways in each cluster. This theme is not explicitly present in clusters 2 and 7, which treat topics closely related to circular supply chains (CSCs) and consumers: this could indicate that these themes haven't been extensively analyzed in direct relation to FW yet.

A keyword co-occurrence network (KCN) analysis was conducted using VOSviewer on the keywords of the papers included in the sample to discover the research trajectories and the most studied concepts and fields. This approach has the underlying assumption that keywords are an adequate description of a paper's content and is expected to expose patterns and trends in a given research field by measuring the association strength between keywords used in publications (Ding, Chowdhury and Foo, 2001). In this type of network, the nodes represent the keywords and the links between them represent a co-occurrence of the terms in the same paper, while the link strength refers to the number of times keywords appeared together: the higher the strength, the more times a pair of keywords has been used together, and the distance between nodes indicates their relatedness. VOSviewer also allows for introducing time as an element for the keyword analysis through the overlay visualization, which can provide information on the temporal appearance of keywords, assigning different colors to different years of appearance to identify research trajectories and recent research topics.

To build the network, both author and indexed keywords have been considered, and a threshold was set to include keywords that appeared together at least five times. To refine the analysis, the set of keywords was normalized. Keywords were all transformed into lowercase, the "s" at the end of words and dots from acronyms were canceled, and different keywords that express the same concept were merged (*e.g.*, supply chain, supply network, and supply chains, merged into supply chain). The keywords that defined the nature of the research paper (*e.g.*, article, systematic literature review, review) were also excluded from the network since they do not provide any information about the topics treated in the document.

The resulting KCN is presented in figure 4: it is composed of 29 nodes and 314 links, for a total link strength of 2461, which shows a strong connection among the network nodes. The keywords with the highest occurrence in the network are 'food loss and waste' (191), 'supply chain' (158), and 'circular economy' (121), in coherence with the structure of the SLR. The concepts of 'sustainability', 'sustainable development', and 'economics' also appear as relevant in the network, highlighting the strong connection of the cardinal topics of the research with environmental, economic, and social sustainability. Interestingly, the keywords 'circular supply chain' and 'sustainable supply chain' are quite distant from 'food loss and waste', so they appear weakly related, despite their relevance in the network. This can indicate that these topics have not been holistically discussed, which also seems to emerge from the cluster analysis of the papers in the citation network.

The overlay visualization of this KCN allows for highlighting the most recent research trends: in this network, the topics of CE and circular and sustainable SCs appear as very recent with respect to the rest of the network, where issues regarding FW appear as broadly discussed in previous years. This temporal indication could explain why these themes have not been jointly discussed much in literature and denote a recent interest in exploring these topics.

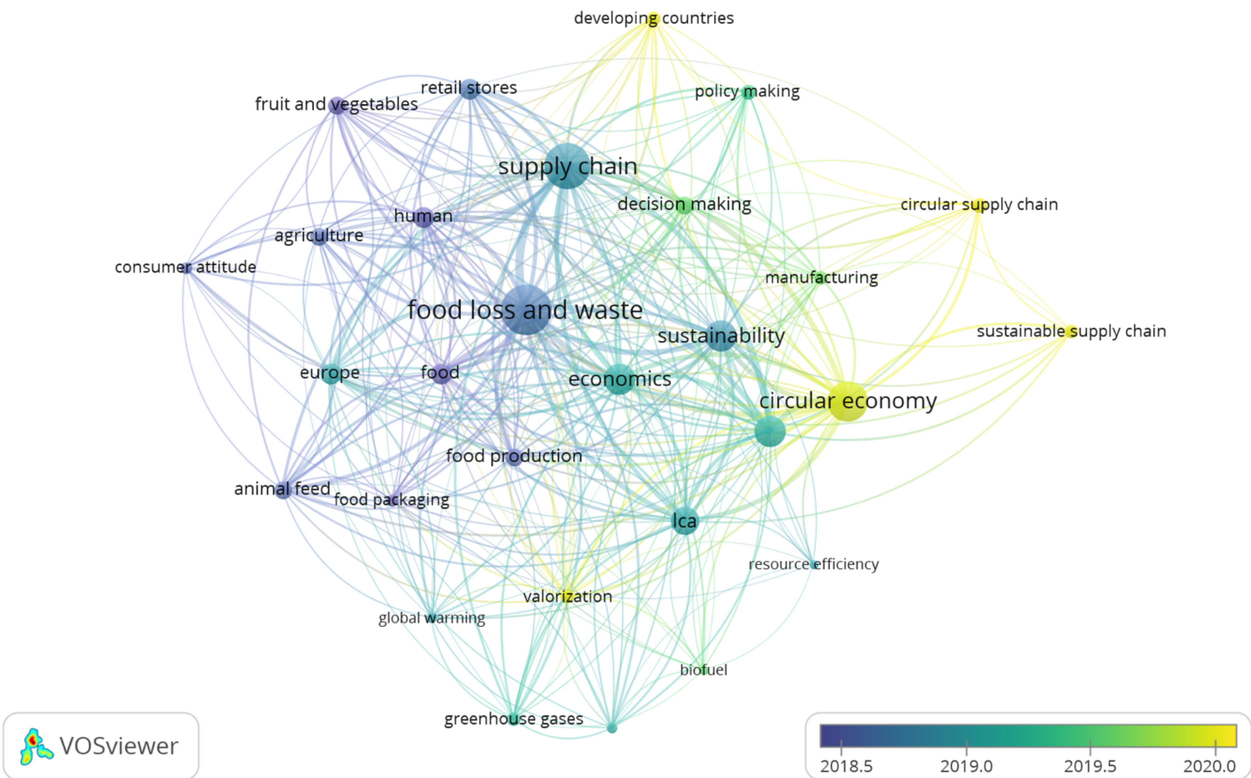

Figure 4 - Overlay visualization of the KCN, obtained with VOSViewer 1.6.17

3.3 Content Analysis

3.3.1 Food waste and circular economy: concepts and practices

As a first emerging theme to guide companies in adopting circular practices, the Ellen MacArthur Foundation developed the ReSOLVE framework, which has become pivotal in the development of value creation mechanisms in a CE context. ReSOLVE is the acronym for Regenerate, Share, Optimize, Loop, Virtualize, and

Exchange, and these actions represent vital points to follow in developing circular systems (Ellen MacArthur Foundation, 2015). In the 2012 report, the Ellen MacArthur Foundation states that CE can be developed both for technical and biological nutrients; these are, respectively, durable components that cannot be returned to the biosphere, and consumables which can safely be returned to the biosphere. To demonstrate the possible looping of the nutrient flows, the report proposes the butterfly graph, which shows possible alternatives for the looping of flows along SCs. From this framework, it becomes clear how biological flows lose value at each consequent loop. As a result, cascading flows represent a suitable strategy. In contrast, inner loops are preferred for technological nutrients since most of the value is retained with respect to external ones (Ellen MacArthur Foundation, 2012). The butterfly graph was used to represent the possible loops of food flows: the version proposed by Teigiserova, Hamelin and Thomsen (2020) better details the graph by distinguishing between edible and inedible flows and proposes some examples for the valorization of FW, also by exemplifying which SC actors might be involved in these projects.

The concept of circularity for food flows is connected to the FWH, developed by E. Papargyropoulou *et al.* (2014). At the top of the FWH is the most favorable option, while other less preferred alternatives are listed in a descending order. These options retain less and less value in the products. The proposed options are prevention, reuse for human consumption through redistribution, recycling into animal feed or via composting, energy recovery, and disposal into landfills (Papargyropoulou *et al.*, 2014). Stemming from this key article, several takes on categorizing and prioritizing the alternatives for FW management have been proposed. A specific hierarchy for biomass (for example, inedible FW) has been developed by Berbel and Posadillo (2018): it ranks the available alternatives, also acknowledging that the favorability of an option is inversely proportionate to the available biomass volume, so when the options become preferable, there is a smaller fraction of biomass suited for that purpose. One of the most recent takes on the FWH was proposed by Teigiserova, Hamelin and Thomsen (2020), where the valorization strategies are described more in detail: prevention is at the top again, followed by reuse for human consumption, reuse for animal consumption, material recycling (where the remaining value is kept bounded to the material), nutrient recycling (which implies a degradation of the material, for example, through anaerobic digestion or composting), energy recovery (in which the material degradation aims at the extraction of energy), and, lastly, disposal. In this paper, the FWH is not only updated, but also connected to the butterfly graph for a more holistic perspective on the potentialities of CE for FW management and reduction: the butterfly diagram shows the path that flows could follow when a certain valorization option is introduced in the SC. The connection of these frameworks better exemplifies that circular actions can be developed at each stage of the food SC and that exchanges between actors can contribute to CE by establishing reverse flows (Teigiserova, Hamelin and Thomsen, 2020).

The plurality of CE practices available to valorize and prevent FW isn't yet reflected in the strategies currently adopted by companies; the studies conducted by Ghisellini and Ulgiati (2020) and Calzolari, Genovese and Brint (2021) have shown how most circular practices are still emerging since a considerable portion of companies only focuses on recycling and using fewer resources. This trend has been confirmed by the study by Oliveira, Lago and Dal' Magro (2021), which underlines how FW solutions mainly have a waste management perspective instead of a CE one.

Despite an increasing familiarity with the CE concept, from a consumer perspective the development of CE relies strongly on the acceptance by consumers of the goods derived from circular practices, and different studies have assessed their attitudes towards these goods. These studies have shown the positive influence of providing information and knowledge about "green" aspects, quality, risk, etc. on purchasing intentions, which are also positively influenced by a cost advantage (Wang and Hazen, 2016; Wang *et al.*, 2020; Stelick *et al.*, 2021). Understanding the consumer's opinion and acceptance level is essential for fostering company actions to valorize FW since safety aspects are extremely relevant. Several studies confirm that in the specific case of food, giving more information to the consumers has benefits regarding the acceptance of circular food products; in particular, knowing the environmental benefits, the complete list and origin of the ingredients, the degree of processing, and why a circular ingredient is used can help increase familiarity with these products (Combest and Warren, 2019; McCarthy, Kapetanaki and Wang, 2019; Coderoni and Perito, 2020; Goodman-Smith *et al.*, 2021; J. Aschemann-Witzel and Stangherlin, 2021). Another aspect that influences the willingness to buy circular food products is the brand that proposes the product: a well-known brand is more likely to be accepted (Aschemann-Witzel and Peschel, 2019).

3.3.2 Causes of food waste in the supply chain

A theme that emerged from the literature analysis regards the causes of FW related to the SC. Causes behind the generation of FW, at all levels of the value chain, depend on the peculiarities of the product and on its specificity, and this results in a wide range of identified causes (Chabada *et al.*, 2015). These also vary along the SC due to the different operations carried out at each step, but some also refer to the SC (Diaz-Ruiz *et al.*, 2018). The found causes are summarized in table 4: they all relate to logistics and SCM aspects, but some are referred to a specific stage of the SC, while others are associated with the distribution network and the relationships between actors. A portion of the identified causes can be found in more than one SC stage and produce effects throughout the whole chain.

Table 4 – Identified causes of FW

Manufacturing and Processing	
Inadequate raw materials / no specifications on raw materials	Bilska *et al.*, 2016; Bilska and Kołozyn-Krajewska, 2019; Goryńska-Goldmann *et al.*, 2021; Kolawole, Mishra and Hussain, 2021
Inaccurate demand forecasting, overproduction	Balaji and Arshinder, 2016; Raak *et al.*, 2017; Bilska and Kołozyn-Krajewska, 2019; Dora *et al.*, 2021
Overstocking	Mena *et al.*, 2014; Balaji and Arshinder, 2016; Chen *et al.*, 2018; Magalhães *et al.*, 2021
Retail	
Broad product assortment and availability on shelves	Food and Agriculture Organization (FAO), 2014; Göbel *et al.*, 2015; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018; Wunderlich and Martinez, 2018; Brancoli *et al.*, 2019; Cicatiello *et al.*, 2020; Magalhães *et al.*, 2021
Inadequate infrastructures	Bilska *et al.*, 2016; de Moraes *et al.*, 2020
Improper inventory policies (product turnover on shelves, estimation of safety stocks)	Wang, Rodrigues and Demir, 2019; Cicatiello *et al.*, 2020; de Moraes *et al.*, 2020; Surucu-Balci and Tuna, 2021
Order policies (minimum order quantity, low delivery frequency)	Chabada *et al.*, 2015; Akkas, Gaur and Simchi-Levi, 2019
Inaccurate demand forecasting	Diaz-Ruiz *et al.*, 2018; Cicatiello *et al.*, 2020; de Moraes *et al.*, 2020; Dora *et al.*, 2021
Promotions and bulk sales	Mena *et al.*, 2014; Canali *et al.*, 2017; Akkas *et al.*, 2019; Ishangulyyev *et al.*, 2019; Magalhães *et al.*, 2021
Logistics network and SCM	

Power imbalances (no agreements, disadvantageous quantity discounts, take-back agreements, shelf life requirements)	Canali *et al.*, 2017; Eriksson *et al.*, 2017; Devin and Richards, 2018; Diaz-Ruiz *et al.*, 2018; Wunderlich and Martinez, 2018; Brancoli *et al.*, 2019; Ghosh and Eriksson, 2019; Ishangulyyev *et al.*, 2019; Ali *et al.*, 2021; Trento *et al.*, 2021
Poor network design, hold ups, and SC aging	Göbel *et al.*, 2015; Balaji and Arshinder, 2016; Akkas, Gaur and Simchi-Levi, 2019; de Moraes *et al.*, 2020; Magalhães, Ferreira and Silva, 2021 Turan and Ozturkoglu, 2021; Yan, Song and Lee, 2021
Lack of adequate infrastructures (vehicles, roads, facilities)	Bilska *et al.*, 2016; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018; de Moraes *et al.*, 2020; Magalhães *et al.*, 2021
Poor handling quality	Arivazhagan, Geetha and Ravilochanan, 2016; Parmar, Hensel and Sturm, 2017; Diaz-Ruiz *et al.*, 2018; Ishangulyyev, Kim and Lee, 2019; Cicatiello *et al.*, 2020; Magalhães *et al.*, 2021
Inadequate packaging	Mena *et al.*, 2014; Bilska *et al.*, 2016; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018; Ishangulyyev, Kim and Lee, 2019; Turan and Ozturkoglu, 2021
Overarching in the SC	
Lack of knowledge, skills, awareness, and training	Bilska *et al.*, 2016; Arias Bustos and Moors, 2018; Diaz-Ruiz *et al.*, 2018; Vats, Gupta and Sharma, 2019; de Moraes *et al.*, 2020; Despoudi, 2021; Lu *et al.*, 2022
Poor leadership and managerial commitment	Bilska *et al.*, 2016; de Moraes *et al.*, 2020; El Bilali and Hassen, 2020
Strong focus on productivity	Messner, Johnson and Richards, 2021; Patel *et al.*, 2021
Legal requirements on food safety	Göbel *et al.*, 2015; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018
Limited capabilities of selling products about to expire	Diaz-Ruiz *et al.*, 2018

In addition to the technical problems that might occur during production, the use of raw materials of inadequate quality is a prominent cause of FW during the processing stage of a food SC ; this risk is increased if no supplier assessment is carried out and there are no quality specifications for the raw material (Bilska *et al.*, 2016; Bilska and Kołozyn-Krajewska, 2019; Goryńska-Goldmann *et al.*, 2021; Kolawole, Mishra and Hussain, 2021). Overproduction is a common issue at the production level but is mainly related to complex or ineffective forecasting and primarily affects the FW derived from fresh and perishable products (Balaji and Arshinder, 2016; Raak *et al.*, 2017; Bilska and Kołozyn-Krajewska, 2019; Dora *et al.*, 2021). Overstocking is a consequence of overproduction, and for products with a short shelf life, or if inadequate inventory management is in place, this can be a relevant source of FW (Mena *et al.*, 2014; Balaji and Arshinder, 2016; Chen *et al.*, 2018; Magalhães, Ferreira and Silva, 2021).

At the retail or wholesale level, one of the most cited causes of FW is the wide variety of products available in large quantities on the shelves throughout the day (Food and Agriculture Organization (FAO), 2014; Göbel *et al.*, 2015; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018; Wunderlich and Martinez, 2018; Brancoli *et al.*, 2019; Cicatiello *et al.*, 2020; Magalhães, Ferreira and Silva, 2021). Due to old or inadequate infrastructures, the number of displayed products that turn into waste increases if the environmental conditions are unsuitable (Bilska *et al.*, 2016; de Moraes *et al.*, 2020).

Furthermore, when not properly managed, inventory policies and controls can be a prominent cause of FW at the retail level, including badly executed stock and product rotation (Cicatiello *et al.*, 2020; de Moraes *et al.*, 2020; Surucu-Balci and Tuna, 2021). Akkas, Gaur and Simchi-Levi (2019) determined that having a minimum order quantity leads to FW due to increased inventory level. Chabada *et al.* (2015) established a correlation between delivery frequency and FW: the higher the delivery frequency, the lower the FW, even if the reduction extent depends on the type of products. The study by Wang, Rodrigues and Demir (2019) highlighted that the amount of safety stocks and how they are calculated could be a driver of FW generation. Inaccurate forecasting is a relevant cause of FW at the retail level, too, where it's affected by the volatility of consumer preferences, which can cause unexpected drops in demand (Diaz-Ruiz *et al.*, 2018; Cicatiello *et al.*, 2020; de Moraes *et al.*, 2020; Dora *et al.*, 2021). Promotions offered in supermarkets have often been pinpointed as a cause of FW as consumers tend to buy more than they need; this behavior is exacerbated by products offered in bulk (Mena *et al.*, 2014; Canali *et al.*, 2017; Akkas, Gaur and Simchi-Levi, 2019; Ishangulyyev, Kim and Lee, 2019; Magalhães, Ferreira and Silva, 2021).

Market power imbalances are often cited as a cause of FW in the SC, as the upstream tiers usually have much lower power than the downstream ones. This translates into practices that damage the growers and suppliers and eventually leads to FW generation (Canali *et al.*, 2017). Some examples include no agreements on volumes to be bought from the producers (Devin and Richards, 2018), agreements with significant quantity discounts (Wunderlich and Martinez, 2018), inadequate linkages with marketing channels (Ali *et al.*, 2021), the 1/3 rule that states the amount of time a product's life should be spent on the retails' shelves (Diaz-Ruiz *et al.*, 2018; Ishangulyyev, Kim and Lee, 2019), and free returns (also defined as take-back agreements, or, TBAs) (Canali *et al.*, 2017). TBAs are agreements for which the supplier must collect the unsold products from the retailer and take care of their disposal. They are particularly common for bread, and several studies have highlighted their negative influence on FW since this responsibility-shifting doesn't incentivize supermarkets to waste less. In some cases, the return rates, and thus the costs, were so high that the supplier eventually decided to stop supplying the retail (Eriksson *et al.*, 2017; Brancoli *et al.*, 2019; Ghosh and Eriksson, 2019). This situation has been analyzed by Trento *et al.* (2021), which highlighted that the paradox created by TBAs could be counterbalanced by a symbiosis between the two parties, where the supplier could offer benefits to the retailer to increase sales and avoid returns.

Poor design of logistics networks can be a cause of FW (Balaji and Arshinder, 2016; de Moraes *et al.*, 2020; Magalhães, Ferreira and Silva, 2021), since it can lead to hold-ups in logistics and SC aging, where products spend most of their shelf lives in the SC instead of in retails or consumers' homes (Göbel *et al.*, 2015; Akkas, Gaur and Simchi-Levi, 2019; Turan and Ozturkoglu, 2021; Yan, Song and Lee, 2021). FW caused by logistics issues is increased by the lack of adequate infrastructures, such as refrigerated storage facilities and vehicles, or good roads, with this lack eventually leading to cold chain inefficiencies or interruptions (Bilska *et al.*, 2016; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018; de Moraes *et al.*, 2020; Magalhães, Ferreira and Silva, 2021).
During transportation, vehicle loading and unloading, cross-docking activities, and the careless handling or mishandling of products frequently results in product damage or spillage, thus leading to waste (Arivazhagan, Geetha and Ravilochanan, 2016; Parmar, Hensel and Sturm, 2017; Diaz-Ruiz *et al.*, 2018; Ishangulyyev, Kim and Lee, 2019; Cicatiello *et al.*, 2020; Magalhães, Ferreira and Silva, 2021). The influence of mishandled products on the generated FW is related to the type of packaging used, whose primary function is to protect the product. Using inadequate packaging or packaging materials that offer low mechanical protection or can be easily damaged increases the risk of food products becoming waste (Mena *et al.*, 2014; Bilska *et al.*, 2016; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018; Ishangulyyev, Kim and Lee, 2019; Turan and Ozturkoglu, 2021).

At each stage of the SC, the lack of knowledge, skills, and training of personnel has been identified as one of the leading causes of FW, which can amplify the structural problems that might be present in the chain (Bilska *et al.*, 2016; Arias Bustos and Moors, 2018; Vats, Gupta and Sharma, 2019; de Moraes *et al.*, 2020; Despoudi, 2021; Lu *et al.*, 2022). Also included as causes of FW in the papers studied were poor leadership and managerial commitment (Bilska *et al.*, 2016; de Moraes *et al.*, 2020; El Bilali and Hassen, 2020), lack of awareness (Bilska *et al.*, 2016; Diaz-Ruiz *et al.*, 2018), limited capabilities of selling products about to expire (Diaz-Ruiz *et al.*, 2018), and a strong focus on productivity (Messner, Johnson and Richards, 2021; Patel *et al.*, 2021). At a higher level, some papers mention the strict legal requirements regarding food safety as a driver of FW generation (Göbel *et al.*, 2015; Canali *et al.*, 2017; Diaz-Ruiz *et al.*, 2018).

3.3.3 Solutions to manage FW in the circular supply chain

A significant portion of the retrieved literature is devoted to the proposal and analysis of solutions to tackle the problem of FW, either by reducing it or through its valorization. According to the objective of this research and following the classification proposed by Diaz-Ruiz *et al.* (2018), this section will be focused on those solutions that can be operationalized in the SC and that require collaboration between two or more SC actors, or are related to logistics and network design (meso level), summarized in table 5. Table 6 lists factors that can facilitate the development of collaborations for the creation of CSCs.

Table 5 – Identified solutions for the management of FW

Collaboration-based solutions	
Reduced product handling and delays, material flow synchronization	Kaipia, Dukovska-Popovska and Loikkanen, 2013; Nguyen et al., 2021
Improved demand forecasting, collaborative forecasting	Liljestrand 2017; de Moraes *et al.*, 2020
Better inventories management (safety stock, automatic replenishment policies)	Liljestrand 2017; Kiil *et al.*, 2018
Introduction of new routines for FW management	Sert *et al.*, 2016
Industrial symbiosis	Rosado and Kalmykova, 2019; Donner, 2020; Dora, 2020
Creation of joint ventures for FW management	Cavicchi *et al. 2021*
Brokerage platforms to match supply and demand of FW	Scazzoli *et al.*, 2019; Ciulli *et al.*, 2020; Mastos *et al.*, 2021
Logistics based solutions	
New, better performing packaging solutions	Liljestrand 2017
Temperature monitoring during transportation, intelligent containers	Haass *et al.*, 2015; Porat *et al.*, 2018, Torres-Sanchez *et al.*, 2021
Improved routing models (to minimize products' quality decay or FW cost)	Rijpkema *et al.*, 2014; Soysal *et al.*, 2015; Fikar, 2018
Development of optimized reverse logistics networks	Accorsi *et al.*, 2015; Bottani *et al.*, 2018; Atabaki, Mohammadi and Naderi, 2020; Liao *et al.*, 2020; Santander *et al.*, 2020; Cao, Liao, and Huang, 2021; Rentizelas *et al.*, 2021; Soleimani *et al.*, 2021; Yildizbasi and Arioz, 2021; Zerbino *et al.*, 2021

Table 6 – Identified factors facilitating the development of collaborations for the management of FW

Top management commitment	Dubey *et al.*, 2019
Clear economic and financial benefits	Gonzàlez-Sànchez *et al.*,2020; Ramkumar 2020
Mutual benefits, shared objectives	Dora, 2020; Gonzàlez-Sànchez *et al.*,2020

Inclusion of core business of both parties in the FW management project	Ramkumar 2020
Definition of collaboration with agreements and contracts	Gonzàlez-Sànchez *et al.*,2020; Ramkumar 2020
Geographical proximity	Dora, 2020
External actor coordinating the collaboration and FW management project	Fischer and Pascucci, 2017; de Oliveira *et al.*, 2019; Rosado and Kalmykova, 2019
Innovative technologies (*e.g.*, blockchain, brokerage platforms)	Scazzoli *et al.*, 2019; Ciulli *et al.*, 2020; Del Giudice *et al.*, 2020; G. Yadav *et al.*, 2020; González-Sánchez *et al.*, 2020; Kayikci *et al.*, 2020; Agrawal *et al.*, 2021; Mastos *et al.*, 2021; Nandi *et al.*, 2021; Upadhyay *et al.*, 2021

At the boundaries between companies, collaboration mechanisms and logistics can influence the amount of FW generated in the SC and the development of CE practices, eventually resulting in circular supply chain management (CSCM) and with the introduction of sustainable practices in the SC (Priefer, Jörissen and Bräutigam, 2016; Dora, 2020). CSCM has been defined as: "*…the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users*." (Farooque *et al.*, 2019). This definition recalls, according to a CE approach, the need to involve all SC functions in the innovation towards circularity and CSCs. Implementing circular practices in the SC has shown to positively correlate with environmental performance, while being subordinated to the attitude of the individual company, which must fully understand the concept of CE and its implications (Hussain and Malik, 2020). Top management has the role of mediating between external pressures and supplier management to develop circular practices, so their commitment and motivation are crucial to transition the SC into becoming more circular and integrated (Dubey *et al.*, 2019). A number of SC mechanisms and dimensions that allow for the design of CSCs have been identified by González-Sánchez *et al.* (2020): greater intensity in the relationships established in the SC, by developing closer and more frequent interactions that entail integrated and synergistic actions by all the parties involved; the adaptation of logistics and companies' organization, given the need for a reverse logistics network; the introduction of disruptive and smart technologies that can allow for better communication and development of new functionalities; and the establishment of a functioning environment through agreements, financial commitments, and shared objectives. The collaboration between SC stakeholders can help address the core issues present in the chain that eventually lead to FW, such as infrastructures, packaging, and adopted standards (A. Bhattacharya and Fayezi, 2021). In the paper by Despoudi *et al.* (2018) seven collaboration paradigms were proposed and explored. The first is 'goal congruence', meaning the presence and extent of shared goals, followed by 'communication' and 'information sharing', indicating how companies communicate and which type of data they share. Shared assets, costs, and risks between the actors are defined as 'resource sharing', and 'incentive alignment'. The joint decision-making process is defined as 'decision synchronization', while the ability to work together to respond to market changes has been described as 'joint knowledge creation' (Despoudi *et al.*, 2018). Similar collaboration aspects have been identified by Arias Bustos and Moors (2018), which described information exchange, incentive alignment, effective partnership, and adequate use of technology as the building blocks of "innovative collaboration", which can be effective in reducing FW. While collaboration is cited as a critical aspect for creating CSCs, Cricelli, Greco and Grimaldi, (2021) argue that the partners should be carefully selected since collaborating with too many parties can have a negative influence on SC innovation.

Information sharing along the SC can be the first step towards coordination for FW reduction as it can streamline the chain, thus reducing product handling and delays and allowing for efficient forecasting and material flow synchronization (Kaipia, Dukovska-Popovska and Loikkanen, 2013; de Moraes *et al.*, 2020; Nguyen *et al.*, 2021). The sharing of information with external stakeholders can create an “extended SC”. For example, by increasing the collaboration between retail and food banks, donations of surplus food can become a daily part of the retail’s routine, allowing for reducing FW, thereby including food banks in the SC (Sert *et al.*, 2016). Beyond simple information sharing, an element cited as crucial in achieving innovation in the SC is “supply chain intelligence integration”, defined as the ability to absorb knowledge from SC collaborators to secure social and environmental benefits (Alonso-Muñoz *et al.*, 2021).

When developing a collaboration or a partnership, achieving mutual benefits is a core aspect (Dora, 2020). Aligning goals between the leading company and the suppliers is crucial, and more favorable conditions can be created if the economic benefits are clear to all parties involved. If the collaboration project doesn’t include the core business of some of the actors, the perceived risks can undermine the success of the project (Ramkumar, 2020). Mutual benefits are achievable even between companies of different sizes, for example with the creation of joint ventures, as presented by Cavicchi and Vagnoni (2021). The presented case involves a cooperative of wineries and a multi-utility company that produces biofuel and energy: their partnership allows the cooperative to have the required capital for plant development while ensuring a continuous supply of feed to the structure (Cavicchi and Vagnoni, 2021).

Trust and active cooperation are important in developing CSCs, but governance instruments can influence these elements. Most of the agreements, relationships, and negotiations are defined with contracts, facilitating the arrangement between companies, and setting the basis for long-term projects and goals. An external actor, such as a technology provider, can also facilitate chain-coordination mechanisms (Fischer and Pascucci, 2017; de Oliveira *et al.*, 2019).

Geographical proximity facilitates collaboration and can result in the establishment of industrial symbiosis (IS) relationships (Dora, 2020). The companies involved don’t usually belong to the same SC but they exchange material and energy flows to reduce the consumption of resources and exploit the products' value at best (Rosado and Kalmykova, 2019). When engaging in IS, companies can maximize their profit and minimize their environmental impact by finding a trade-off between the two objectives (Vimal, Rajak and Kandasamy, 2019). The project developed in the city of Göthenburg, reported by Rosado and Kalmykova (2019), involved four distinct value chains (lamb, fruit and vegetables, beef, chicken) in developing an IS network. The project required coordination by the developer companies to identify value chains, stakeholders, infrastructures, and flows. The involvement of stakeholders and the understanding of their activities has allowed for the development of the IS network, which is associated with the adoption of circular practices, and which contribute to sustainable development (Rosado and Kalmykova, 2019). Examples of IS can be found at the agricultural level as well: agroparks that rely exclusively on the exchange of bio-based flows between different stakeholders present in the area can be developed (Donner, Gohier and de Vries, 2020).

Logistics solutions can reduce FW, and these can require collaboration between SC actors (Liljestrand, 2017). When transporting food products, packaging protects the items from damage; thus, adopting new and better performing packaging solutions can reduce the amount of FW (Liljestrand, 2017). To minimize waste, intelligent packaging can provide information about quality decay, which can be used to allocate products between producer and retailer (Heising, Claassen and Dekker, 2017).

Temperature monitoring during transportation allows for keeping the products at the optimal storage temperature, thus minimizing the FW caused by interruptions in the cold chain. This technology can also be implemented in refrigerated containers, for example, for long-route transportation (Porat *et al.*, 2018), allowing for real-time communication of the temperature (Torres-Sanchez *et al.*, 2021). Intelligent containers that are able to calculate the remaining shelf life, start controlled ripening, and eventually communicate product spoilage are excellent ways to tackle FW, since they have been shown to reduce it by 22% (Haass *et al.*, 2015). Routing models that include the quality decay of products and the costs associated with waste have also been developed. One of the goals is to reduce FW while increasing the quality of the products delivered to the customer (Rijpkema, Rossi and van der Vorst, 2014; Soysal *et al.*, 2015; Fikar, 2018).

Warehouse management can be improved through information sharing between SC actors. The shared data can be used for collaborative forecasting to revise the product groups (if some show particularly high levels of FW), to define the level of safety stocks, and better manage the lead time (Liljestrand, 2017). Replenishment policies can also be optimized thanks to information sharing. This can be achieved with automatic replenishment policies, where highly granular data about each SKU are shared with the supplier: an order proposal is generated according to these data, which can be accepted or denied. The introduction of automatic replenishment policies has shown to be particularly effective in reducing the FW of products with long shelf life (around 20%) (Kiil *et al.*, 2018).

The development of CSCs requires establishing new relationships and, possibly, a reverse logistics network. The changes needed in the SC structure and how to optimize the new network have been explored in several papers. It is important to note that the configuration of a CSC is influenced both by the external and internal environments, and a tendency to self-organize is often shown. The resulting supply networks can be open loop (where flows circulate outside the original SC, thanks to another actor), closed loop, or a hybrid of the two (Braz and Marotti de Mello, 2022).
Some use mixed-integer linear programming, setting the minimization of costs and the maximization of the environmental benefits as objectives. Applying these models in the design of CSCs shows the feasibility of developing an optimized reverse logistics network (Accorsi *et al.*, 2015; Bottani *et al.*, 2018; Atabaki, Mohammadi and Naderi, 2020; Liao *et al.*, 2020; Santander *et al.*, 2020; Rentizelas *et al.*, 2021; Soleimani *et al.*, 2021; Yildizbasi and Arioz, 2021). The circular network might have different configurations and involve different players. One example is a two-echelon network, where one part is devoted to collecting waste from consumers, and the second one to delivering the collected waste to recycling centers (Cao, Liao and Huang, 2021). Other configurations might entail the presence of a "formal scavenger", an actor in charge of the collection of waste from different sources, which allows for mitigating the risk and cost of procurement (Zerbino *et al.*, 2021).

Other studies have focused their attention on the dynamics that arise in the CSCs. Flow uncertainties affect the inventory performance of the SC, while they don't have significant consequences related to the bullwhip effect, which is generally reduced in CSCs, even with long and variable lead times. On the contrary, circular chains seem to benefit from long lead times, this dynamic being defined as "lead time paradox" (Dominguez *et al.*, 2020). The centralization of the remanufacturing processes can reduce flow uncertainties, thus allowing for smoother production and more efficient logistics (Dominguez, Cannella and Framinan, 2021).

The transition towards CSCs can be facilitated with innovative and disruptive technologies, which enable coordination and collaboration among SC members, digitization of SC activities, and the integration of digital and physical systems to improve the CE performance of the SC (Del Giudice *et al.*, 2020; González-Sánchez *et *al.*, 2020; Yadav *et al.*, 2020; Agrawal *et al.*, 2021). Blockchain, which can provide trustable, transparent, and secure data, can help strengthen the relationships across the SC. This technology allows for localizing the materials in the SC, thus increasing visibility and traceability and eventually improving the sustainability and resilience of the whole chain with the development of secure systems and smart contracts (Nandi *et al.*, 2021; Upadhyay *et al.*, 2021). In the FW context, blockchain technology has potentialities to track waste and losses, understand the causes, and track redistribution flows (Kayikci *et al.*, 2020; Mastos *et al.*, 2021). Blockchain could also be employed to match supply and demand of waste with the development of a bidding platform that allows for a real-time information exchange and SC integration (Mastos *et al.*, 2021). Brokerage platforms represent a technology that is particularly suited to closing the loop of FW. They can be either B2B, B2C, or C2C. They don't only allow for matching supply and demand, but can also inform about the problem of FW, mobilize stakeholders, integrate the users, and measure the avoided impacts (F. Ciulli, Kolk and Boe-Lillegraven, 2020). SIVEQ is an IoT-based platform connecting retailers with food banks. It can be accessed with a mobile app wherein donors upload the available products, enabling the receiver to navigate the food that is up for donation and be notified when the food can be retrieved (Scazzoli *et al.*, 2019).

4. Discussion

The adoption of the CNA and of the content analysis for this literature review allowed for deriving complementary perspectives that offer a comprehensive overview of the field under study. In particular, the bibliometric techniques – thanks to the citation score analysis, the papers' cluster analysis and the KCN - allowed for shaping the structure of the existing body of knowledge in terms of main emerging areas of study and research trajectories, and the level of relatedness of the various emerging themes. On the other hand, the content analysis allowed further themes to emerge in terms of concepts, practices, causes, and solutions related to food waste. Taken all together, the perspectives adopted in the analysis of the literature allow for deriving a set of insights on the body of knowledge and on the state of the art related to FW, CE, and food SCs. The findings that arose from this multi-perspective analysis are presented below, where the main concepts are presented with propositions. Table 7 summarizes the propositions, by also highlighting the main references from which they have been derived. Taking into account the findings of this review, outlined with propositions, the authors suggest possible avenues for future research.

Table 7 – Propositions and further research directions

	Main references	**Proposition**	**Research direction**
1	*Ellen MacArthur Foundation, 2012; Ghisellini and Ulgiati, 2020; Teigiserova, Hamelin and Thomsen, 2020; Oliveira, Lago and Dal' Magro, 2021; T. Calzolari, Genovese and Brint, 2021*	Tailoring CE frameworks and guidelines to the whole food SC is crucial to move away from a waste management approach to FW towards the development of CSCs aimed at FW reduction and valorization	Investigate and systematize how CE principles are operationalized in food SCs for the reduction and valorization of FW, to highlight effective approaches for the creation of CSCs in the food industry
2	*Chabada et al., 2015; Canali et al., 2017; de Moraes et al., 2020; Magalhães et al., 2021*	Along the entire food SC, within companies and at the boundaries between them, there are sources of FW that can vary based on the characteristics of different food products	Study and compare how FW is managed along different products' value chains, to highlight the most common approaches at each step of the chain, by also considering how the peculiarities of each food

			product might influence the adopted FW management strategies
3	*Kiil et al., 2018; de Moraes et al., 2020; González-Sánchez et al., 2020; Hussain and Malik, 2020; Ramkumar, 2020*	Collaborations between companies to prevent the generation of FW or to exchange waste flows can facilitate the introduction of CE principles in food SCs and the development of CSCs, enabled by cross-functional teams	Explore and determine how collaborations between companies can generate benefits from a FW perspective and overall facilitate the introduction of CE practices in the supply network
4	*Fischer and Pascucci, 2017; de Oliveira et al., 2019; Rosado and Kalmykova, 2019; F Ciulli, Kolk and Boe-Lillegraven, 2020*	The presence of an external actor in charge of overseeing and coordinating FW related projects can facilitate the collaboration between companies, the introduction of CE principles in food SCs, and the development of CSCs	Outline and define the facilitating role of a third-party actor, which could play a pivotal role in the creation, management, and coordination of circular networks, but also facilitate the development of collaborations aimed at the reduction and valorization of FW
5	*Liljestrand, 2017; Scazzoli et al., 2019; F. Ciulli, Kolk and Boe-Lillegraven, 2020; Kayikci et al., 2020; Mastos et al., 2021;*	The development of CSCs aimed at the reduction and valorization of FW can be facilitated by the adoption of innovation and technologies (e.g., packaging, blockchain, brokerage platforms) when these span across the SC beyond the boundaries of single organizations, to support CE projects that involve multiple companies	Investigate and describe the role of innovative technologies in the establishment of collaborations among different actors for the development of CE projects at SC level for FW reduction and valorization
6	*Coderoni and Perito, 2020; J Aschemann-Witzel and Stangherlin, 2021*	The introduction of CE projects aimed at the reduction and valorization of FW in food SCs can result in the production of circular products, which need to be appropriately developed and marketed by companies to foster consumer acceptance	Explore and outline consumers' perspective in terms of acceptance of circular food products and buying behavior to guide companies' actions towards wider introduction of circular products

The integration of CE in the SC, described with the concept of CSCM, appears to be a promising approach for reducing FW, since FW is generated all along the chain, inside companies, but also at the boundaries between them (see table 4), due to conditions that also depend on the characteristics of different product groups (Chabada *et al.*, 2015). Despite the several frameworks proposed in the literature, an effective approach to integrate the CE in food SCs seems to be lacking. The fact that there is a lack of literature that holistically discusses these topics clearly emerged from the CNA as well, through the KCN, where the topics of FW and CSC appear as weakly related to each other (see figure 4). The same analysis, thanks to the overlay visualization of the KCN, also underlines an emerging interest in these themes. The implementation in SCs of general guidelines about CE and FW, such as the FWH or the butterfly graph (Ellen MacArthur Foundation, 2012; Teigiserova, Hamelin and Thomsen, 2020), is still scarce and not well documented in the scientific literature. This is also testified by the strategies adopted by companies, that have a focus on waste management, instead of endorsing the holistic approach of CE and operationalizing it in the SC (Ghisellini and Ulgiati, 2020; Oliveira, Lago and Dal' Magro, 2021; T. Calzolari, Genovese and Brint, 2021). The underlying lack of knowledge and culture about these topics increases the difficulties in translating these paradigms into practice (Tura *et al.*, 2019). Overcoming such barriers can be crucial to develop effective strategies in the SCs for FW management built on CE principles.

Proposition 1 *Tailoring CE frameworks and guidelines to the whole food SC is crucial to move away from a waste management approach to FW towards the development of CSCs aimed at FW reduction and valorization.*
Proposition 2 *Along the entire food SC, within companies and at the boundaries between them, there are sources of FW that can vary based on the characteristics of different food products.*

Partnerships and coordination between SC actors can prevent the generation of FW, for example with the introduction of contracts that define balanced agreements that reduce market power imbalances (i.e., avoiding TBAs that damage the supplier) (González-Sánchez *et al.*, 2020; Ramkumar, 2020) or with the development of new practices, such as collaborative forecasting (de Moraes *et al.*, 2020) or automatic replenishment policies (Kiil *et al.*, 2018). As seen from both the CNA and the content analysis of literature, different SC functions might be involved in the management of FW. For example, product development would be concerned if new packaging were introduced (Liljestrand, 2017), or logistics might come into play for the introduction of improved routing models (Rijpkema, Rossi and van der Vorst, 2014; Soysal *et al.*, 2015; Fikar, 2018). When companies decide to collaborate, the sharing of information, skills and knowledge can facilitate the development of innovative solutions to tackle FW. The novel solutions might entail a partial reconfiguration of the supply network, and the presence of a third party in charge of the flows management could facilitate a shift towards a more circular SC, for example by matching supply and demand of waste flows (see for example Rosado and Kalmykova, 2019; F Ciulli, Kolk and Boe-Lillegraven, 2020). The establishment of new practices devoted to FW reduction might also require the introduction of new technologies, hence the presence of a third actor with the role of technology provider, that could boost and simplify the implementation process (Fischer and Pascucci, 2017; de Oliveira *et al.*, 2019).

Proposition 3 *Collaborations between companies to prevent the generation of FW or to exchange waste flows can facilitate the introduction of CE principles in food SCs and the development of CSCs, enabled by cross-functional teams.*
Proposition 4 *The presence of an external actor in charge of overseeing and coordinating FW related projects can facilitate the collaboration between companies, the introduction of CE principles in food SCs, and the development of CSCs.*

The CNA and the content analysis let technology and innovation emerge as key enablers for a CSC, both in terms of IT solutions and the improvement of existing assets and practices (*e.g.*, better performing packaging (Liljestrand, 2017), improved warehouse management (Liljestrand, 2017; Kiil *et al.*, 2018), and optimized transportation (Rijpkema, Rossi and van der Vorst, 2014; Soysal *et al.*, 2015; Fikar, 2018)). The use of technologies also represents a significant body of literature in the context of FW, as confirmed in the CNA, where one cluster devoted to this topic has clearly emerged (cluster 7, see figure 3). From an SC perspective, technology is no longer a tool that is employed by the stand-alone company, but one that can be tailored to the SC to optimize and improve its dynamics and processes. The exploitation of the potential offered by new technologies would allow for the creation of CSCs, where the exchanges at the interfaces between companies are facilitated, and the benefits of CE in food SCs are shared among players; some of the identified technologies are blockchain-based (Kayikci *et al.*, 2020; Mastos *et al.*, 2021), while others rely on brokerage platforms to match the supply and demand of FW, even with the employment of IoT (Scazzoli *et al.*, 2019; F. Ciulli, Kolk and Boe-Lillegraven, 2020).

Proposition 5 *The development of CSCs aimed at the reduction and valorization of FW can be facilitated by the adoption of innovation and technologies (e.g., packaging, blockchain, brokerage platforms) when these span across the SC beyond the boundaries of single organizations, to support CE projects that involve multiple companies.*

Consumers appear to play a role in defining how SCs and companies deal with FW. Despite the fact that the consumption stage is beyond the scope of this SLR, the relevance of the consumers' perspective is testified by the studies devoted to exploring the acceptance of circular food products (see for example Coderoni and Perito, 2020; J Aschemann-Witzel and Stangherlin, 2021). The CNA underlines their relevance, even if the exploration of these dynamics is still partially disconnected from the study of FW, since the cluster discussing such topics is not strongly connected with the ones discussing FW. Despite this disconnection, the introduction of valorization strategies for FW can result in the production of circular products, which companies should be able to successfully market to achieve the economic sustainability of the project.

Proposition 6 *The introduction of CE projects aimed at the reduction and valorization of FW in food SCs can result in the production of circular products, which need to be appropriately developed and marketed by companies to foster consumer acceptance.*

5. Conclusions and research directions

Drawing from the propositions that have been developed, this SLR allows outlining some possible research topics that can potentially deepen and expand the knowledge about circularity in food SCs. Table 7 exemplifies the links between the presented propositions and potential further research directions, discussed in the following paragraph.

Proposition 1 stresses the importance of investigating how food SCs deal with CE, for example, by adopting a case-study approach to gather insights on how CE principles can be operationalized in real SCs with the aim of reducing FW. The study should focus on those projects that go beyond the traditional waste management approach and that are oriented towards the development of CSCs, where the exchanges of flows between actors are facilitated and the whole SC is engaged in pursuing the objectives of CE; this would help to narrow the gap highlighted in this paper between the fields of FW management and CSCs. A systematic analysis of such projects could also demonstrate best practices and recurring mechanisms, contributing to making these practices mainstream in the fight against FW.

Proposition 2 focuses on the sources of FW, which depend on the characteristics of different food products, and can be found all along the food SC, also at the interfaces between companies. The causes of FW have been thoroughly and systematically investigated in literature, also in relation to mitigation strategies, but little attention has been devoted to studying how the peculiar characteristics of different food products might impact the FW mitigation strategies as well. The authors believe that a more in-depth study of this aspect can provide a more detailed perspective of the development of CSCs, yet maintaining a holistic approach by considering food SCs as a whole. Deepening these aspects can contribute to the definition of the most common approaches to introduce circularity in food SCs, with a focus on each step of the SC (and also on the interfaces between actors), and on the influence of the specific features of each food product (e.g., shelf life, conservation temperature, etc.). Comparing how value chains face the problem of FW could also provide insights on how different SCs might rearrange to accommodate FW management solutions, thus offering a further level of analysis that encompasses the entirety of the SC.

In studying these topics, attention should also be devoted to the collaborations companies could establish to develop circular solutions for FW management, as suggested in proposition 3. Evidence of the relevance of collaborations in this field have partially emerged from the analyzed sample, and further research could be devoted to exploring this topic more in detail. The study could focus on exploring the relation between collaboration among companies and benefits from a FW perspective, by eventually developing indicators to quantify the advantages brought by the introduction of collaborations, which have the potential of facilitating the introduction of CE practices in the supply network and the consequent development of CSCs.

As stated in proposition 4, studying these mechanisms might also contribute to defining the facilitating role of a third-party actor, which has been found to be critical in some articles retrieved in literature. It has been discussed how an external facilitator can play a pivotal role in the creation, management, and coordination of circular networks. This research avenue is also strongly tied with proposition 3, since the external actor can facilitate the development of collaborations aimed at the reduction and valorization of FW in the context of CSCs development. Considering the typically higher geographical dispersion of SCs, a third-party facilitator could be crucial for the establishment of open loop and closed loop SCs to match supply and demand, harmonize the product flows, and more in general oversee the management of the CE projects.

From proposition 5 it appears clear that technologies can be tailored to the need of food SCs to allow for an easier development of circular strategies for FW, that are likely to involve more than one actor. Taking the previous considerations into account, further research could investigate the role of innovative technologies, such as blockchain or IoT, in the establishment of collaborations for FW management. In particular, the research could describe how they can be employed to foster the development of partnerships aimed at the reduction of FW and at the creation of CSCs. The research scope could also be enlarged to include the external facilitator in the analysis, since in some cases this actor corresponds to the technology provider.

As a final remark, as stressed in proposition 6, evaluating the consumers' perspective and role in the SC with regards to the acceptance of circular food products can provide insights and guidance to finding solutions to implement in food SCs. The opinion of consumers on the purchasing and consumption of food products derived from FW is an emerging theme in the literature, as delineated both in the CNA and in the content analysis. Deepening the knowledge on this topic can bring to light the most suitable solutions to valorize FW to develop, produce, and market products that can be well-received by consumers, to effectively close the loop of nutrients.

In terms of theoretical implications, the present study can help rationalize the wide body of literature available on the theme of FW. Through the proposed clustering, the CNA carried out on the paper sample depicts a clear picture of the most common research themes, as well as of the emerging ones, especially thanks to the KCN. The adopted SC perspective gives novel insights on how CE is currently operationalized in food SCs, towards the development of CSCs; despite the significance of the analyzed contributions, this topic appears to be, overall, understudied in the context of FW. The developed propositions provide a concise overview of the main findings of this SLR, which can frame the currently studied topics regarding the development of circular practices for FW in SCs and highlight the existing research gaps. The overview presented in table 7 can serve as guidance for researchers to investigate these understudied themes and potentially increase the knowledge in the field.

The current study can also help practitioners to understand the context of FW, CE and SCs, become aware of the most common causes of waste, and acknowledge the existence of remedial solutions. The laid-out propositions allow for isolating those elements that can be leveraged to develop innovative and more effective approaches towards the reduction of FW in food SCs to ultimately plan and implement actions, projects, and initiatives towards this aim.

Despite these contributions, this work has some limitations. The articles have been collected only from the Scopus database, which, while having a very wide collection of publications, does not include all the articles ever published. A further limitation could be related to the choice of only analyzing papers published from 2012 on. Despite the clear reasoning behind this choice, which was dictated by the date of the official definition of CE by the Ellen McArthur Foundation, excluding older papers might prevent the researchers from obtaining insights on the antecedents and roots of this field of study.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Compliance with Ethical Standards

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Disclosure of potential conflicts of interest

All the authors declare that they have no conflicts of interest.

Research involving human participants and/or animals.

No human participants and/or animals have been involved in this research.

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