# Reducing food loss and waste in supply chain operations

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## Abstract

This paper presents a review of research on food loss and waste (FLW) from the perspective of operations management (OM). Supply chain FLW represents a significant challenge for researchers and practitioners grappling with issues of famine and inequitable access to food supplies. Our broad literature pool includes 346 articles published in prestigious OM, management, and prominent economics, environment, and food science journals. The contribution of this review is threefold. First, we provide insights into FLW studies from the lens of specific stages within the food supply chain and from the perspective of the entire food supply chain. Second, we identify overarching research themes in the FLW literature. Third, we draw insights from our literature sample, presentations in the leading OM conferences, working papers, and 30 semi-structured interviews of food supply chain stakeholders to provide a projection of future research opportunities. Such a review approach ensures our analysis being relevant to practice.

**Keywords:** Food supply chain, Food loss and waste, Food waste management, Operations management, Literature review

**Article Classification:** Full Length Article

## 1. Introduction

Despite considerable inroads being made in the reduction of worldwide hunger, almost 690 million people, or 8.9 percent of the world's population, were deemed undernourished (Food and Agriculture Organization [FAO], 2020a), and 135 million people were identified with severe food shortages in 2019 (The World Food Program, 2020). More recently, the COVID-19 pandemic has caused a massive global economic downturn and serious food crises (FAO, 2020b). Indeed, FAO (2020a) projects that the number of undernourished people will be somewhere between 773 and 822 million as a result of the pandemic. The combination of movement restrictions, lockdown policies, and international trade closures makes the pandemic an acute threat and challenge to food systems (FAO, 2020b), particularly in relation to the availability of, and disruptions to, food supplies and the overall uncertainty surrounding food demand (FAO, 2020c). Amidst these increasing concerns, "Save food" and "Moving forward on food loss and waste reduction" have been highlighted as global initiatives (FAO, 2021).

Therefore, food loss and waste (FLW) reduction has emerged as a critical objective for the world (Hamilton and Richards, 2019); in addition, it makes direct contributions to achieving the United Nations' Sustainable Development Goals No.2 (zero hunger) and No.12 (responsible consumption and production) (United Nations, 2022). Fifty-nine international organizations are working on FLW reduction worldwide (Foodbank, 2016), and national and international agencies have made significant efforts towards and commitments to FLW reduction over the past decade. For example, in 2015, the European Commission and the U.S. Department of Agriculture set goals to halve food waste at the downstream end of the food supply chain (FSC) by 2030. In 2016, New Zealand conducted the action – "Love Food Hate Waste" to help people reduce food waste. In 2019, to highlight the importance of FLW reduction, the 74$^{th}$ United Nations General Assembly designated 29 September as the International Day of Awareness of Food Loss and Waste (United

Nations, 2021). Italy, Japan, and China promulgated anti-food waste laws and regulations in 2016, 2019, and 2021, respectively.

The FAO (2011) estimates that around 1.3 billion tons (valued at 1.2 trillion US dollars) of edible food for human consumption is lost or wasted – enough to feed about 97% of the undernourished population (FAO, 2018). The United Nations Environment Program (UNEP, 2021) estimates that around 931 million tons of food were wasted in the downstream FSC in 2019. Furthermore, lost or wasted food consumes resources equivalent to almost one-third of available agricultural land, freshwater, fertilizers, and pesticides used in production (FAO, 2018); it accounts for 8-10% of total anthropogenic greenhouse gas emissions, ranking as the third top emitter after China and the U.S. if considered as a country (FAO, 2015). FLW is also regarded as an inefficiency within the FSC (Corrado and Sala, 2018). According to Govindan (2018), 23% of FLW could be reduced by more effective FSC management methods. FLW reduction is increasingly regarded as central to FSC management (Kourmentza et al., 2018).

Historically, Operations Management (OM) scholars have paid less attention to FLW reduction in contrast to other streams of research in FSC management, such as issues of traceability (e.g., Aung and Chang, 2014), network design (e.g., Yu and Nagurney, 2013), and transportation and storage (e.g., Validi et al., 2014). However, increasing concerns about the economic, moral, and environmental effects of FLW have elevated the need to effectively reduce FLW by optimizing the FSC and have amplified the need to study FLW issues from an operational lens.

Our research was initially motivated by a conversation with a department director working in the Chinese government in 2018, who approached us to seek help in relation to how to improve FLW by managing general operations and using government interventions. We therefore started to scrutinize the literature and identified that there were limited studies focusing on FLW issues from an OM perspective. We reached out to operations managers, marketing mangers, heads of cooperatives, executives, etc. from different constituents of FSCs, including food manufactures, farmers' cooperatives, wholesalers, importers, e-commerce companies, supermarkets, third-party logistics providers, governments, and non-governmental organizations (NGOs) to acquire first-hand information regarding the FLW situation.

We conducted 30 semi-structured interviews with participants from both large companies and small and medium-sized enterprises (SMEs), governments, and NGOs in China. The practitioners, governments, and NGOs all noted the importance of FLW, although their foci are slightly different. For instance, a senior director at a leading food processing company stated that “In our company, the food loss rate is around 0.5% in the processing stage, and 2-3% in the sales stage”. Compared with this food processing company (overall less than 3.5% food loss), the estimation of food loss is much higher in a famers’ cooperative. The head of a cooperative explained that “Food loss and waste always occurs in the sales stage because not all fruit can be sold in a timely manner. The loss rate is around 5-10% for the ones in good appearance and size, and around 30-40% for the suboptimal fruits (small size or/and ugly food), even when there is no quality problem.” Another logistics manager at a leading beverage company summarized that “The food loss and waste issue is very serious in our company because its reduction can decrease overall costs and increase profit.” (Note, all quotes are translated from Chinese and have been paraphrased for clarity.)

Governments and NGOs address FLW issues mainly from national and global perspectives. An associate director from the Chinese government highlighted that “FLW as an important activity contributing to the sustainable development and carbon neutrality strategies has attracted more attention worldwide recently” and “In China, the average FLW rate is considerably high in all stages of FSC. It not only impacts the revenue of FSC stakeholders, but also China’s food security” In addition, a director at an NGO stated that “COVID-19 pandemic caused more customer concerns on food security and food availability owing to the lockdown policy. The government, food industry, and society are paying more attention to FLW reduction”.

Considering the importance and meaningfulness of FLW topics indicated in our interactions with practitioners, governments, and NGOs, we explore the current state of research on FLW reduction. In our study, we scrutinize publications focusing on FLW reduction from an OM perspective and address three research questions:

**Q1:** What are the FLW topics covered in present studies in FSC?

**Q2:** What are the research themes and methodologies employed in the current literature?

**Q3:** What opportunities are there for future research in this area?

In contrast to a typical literature review paper which only considers academic research, this work is developed in a distinctively different way for which we coin a term "relevance-driven literature review". We define relevance-driven literature review as a literature review that is motivated by the problems and needs in practice and informed by insights from empirical data, especially in discussing future research directions. Such an emerging review approach is employed by Choi et al. (2018) and Zhang et al. (2021), both of which survey not only academic research but also implementation cases in practice to ensure the relevance of the review works. This innovative review approach overcomes the relevance gap between research and practice which has been widely criticized as a grand challenge in the management research (Tranfield & Denyer, 2004).

We organize this paper as follows. Section 2 explains the theoretical background. Section 3 outlines the review methodology. Section 4 presents sample statistics. Sections 5 and 6 review the selected papers from the perspectives of research questions and research themes, respectively. After summarizing the key studies, we discuss the knowledge gaps that remain and suggest future directions for research in Section 7.

## 2. Theoretical background

The FLW literature uses a wide range of terms, sometimes inconsistently. For instance, "food supply chain", "food value chain", "food system", and "food chain" are all used in the literature, sometimes synonymously (Östergren et al., 2014). Moreover, the definition of, and the distinction between, food loss and food waste vary greatly in the literature (Beretta et al., 2013). The interchangeable use of such terms may confuse OM researchers undertaking work in this area. Thus, this section discusses the key definitions that have emerged in the literature and clarify the concepts and perspectives involved.

*2.1. Food supply chain, food value chain, food system, and food chain*

Table 1 outlines the differences between the terms FSC, food value chain, food system, and food chain, and the elements they involve. FSC management focuses on the operational problems and challenges in managing food product, information, and financial flows across multiple stakeholders. It is mainly concerned with operations-based activities including production, storage, transportation and distribution, processing, wholesale, retail, and consumption. Given that FSC management typically deals with multiple stakeholders, a key emphasis is on cooperation between the upstream and downstream actors (Halloran et al., 2014; Bustos and Moors, 2018). Cost efficiency has been a key performance measure in FSC management. In recent years, however, FSC management has been giving more attention to sustainability performance, for example, improving resource circularity (Farooque et al., 2019a; Coderoni and Perito, 2020).

**Table 1** Comparison of the terms food supply chain, food value chain, food system, food chain

| Terms | Definition | Operations-based Activities | Other elements involved | Emphasis | Other synonymous or specialized terms applied |
|---|---|---|---|---|---|
| Food Supply Chain[*] | "All the activities that help ensure the delivery of finished products to the consumer from the primary producer" | Production, storage, transportation and distribution, processing, wholesale, retail, consumption | Product, information, and financial flows across multiple organizations and customers | Cooperation between the upstream and downstream, efficiency, sustainablility, etc. | Agri-food supply chain, agri-business supply chain, etc. |
| Food Value Chain[**] | "A systematic structure that coordinates all agents and their economic activities within a food chain" | Farming, processing, waste disposal, packaging, marketing, logistics | Processes or activities by which customer value is formed | Economic activities, value added analysis, etc. | Agri-food value chain, agro-food value chain, sustainable food value chain, etc. |
| Food System[*] | "The sum of all the diverse elements and activities which, together, lead to the production and consumption of food, and their interrelations" | Production, processing, distribution, preparation, consumption | Resources, environment, climate, energy, consumer, inputs, outputs, processes, infrastructures, etc. | A macroscopic view, food security, sustainability, etc. | Agri-food systems, agro-food systems, sustainable food systems, local food systems, industrialized food systems, etc. |
| Food Chain[*] | The practices and activities from harvest to consumption | Production, processing, distribution, preparation, consumption | Microbiological safety, food safety, energy, public health, nutrition, etc. | A macroscopic view, food chain crisis, food chain structure, sustainability, etc. | Food supply and distribution chain, agri-food chain, fast food chain, aquatic food chain, trophic food chain, etc. |

[*] HLPE, 2014. Food losses and waste in the context of sustainable food systems. A report by the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome 2014.

[**] FAO, 2015. Food system analysis versus value chain analysis: a conceptual approach for "meeting urban food needs".

In contrast to FSC management, food value chain management studies the economic activities in the FSC by which customer value is created. It is also concerned with operations-based activities including farming, processing, and logistics. However, relatively speaking, it has a greater interest in waste disposal, packaging, and marketing activities, all of which can have a direct and substantial economic impact. From the viewpoint of value creation, food value chain management focuses on processes or activities by which customer value is formed. Consequently, management attention is mainly on economic activities and value-added analysis.

Food system and food chain, which are often applied synonymously, are broader concepts, involve more elements, and interface with a wider range of other systems (HLPE, 2014). A food system is defined as "the sum of all the diverse elements and activities which, together, lead to the production and consumption of food, and their interrelations" (HLPE, 2014, p. 29). It involves not only operations-based activities at a micro (firm/supply chain) level, but also other elements at the meso and macro levels including resources, environment, climate, energy, infrastructures, among others. A food chain includes all the stages from food harvest to consumption. It shares a macroscopic view with the term food system but involves other elements including microbiological safety, food safety, energy, public health, nutrition, etc.

A precise application of these terms in relation to FLW issues is important to facilitate understanding of the occurrence, value, and root causes of FLW. For example, FLW may occur during the transportation or storage process in a fragmented FSC with multiple tiers due to a cooperation issue, or within a vertically integrated company that inefficiently manages its food value chain. Interfaced with other systems, such as energy, resource, and microbiology, FLW problems are also investigated as a key issue within food systems or food chains. For the purposes of this paper, which adopts an OM lens, we focus on how FLW can be reduced by efficiently managing the FSC.

*2.2. Food loss and food waste*

The terms “food loss”, “food waste”, “food loss and waste”, “food wastage”, and “post-harvest losses” have been used interchangeably in FLW research (HLPE, 2014), leading Garcia-Herrero et al. (2018) to contend that the lack of standard definitions is a prominent problem for FLW studies.

Food loss and food waste have many differences when their definitions are respectively unpacked, and these present distinct operational and managerial challenges for OM research. One way of distinguishing between the concepts is whether the decrease in food quantity is natural (food loss) or behavioral (food waste). Another distinction involves whether the occurrence is located at the upstream stage (food loss) or the downstream stage (food waste) of the FSC. Table 2 summarizes the key differences between the terms.

**Table 2** Comparison of food loss and food waste

| Distinction between food loss and food waste | Food Loss | Food Waste | Possible Advantage or Limitation |
|---|---|---|---|
| The stage of the food chain (Physical occurrence at different stages) | Upstream stages (Before consumption) | Downstream stages (Retail or consumer level) | Helps to identify the food waste issues that are related to retailers’ and consumers’ behavior, and food loss issues that are related to logistical and infrastructural limitations |
| Usage of the food | Decrease in food products for human consumption | Decrease in food products not for human consumption | Distinguishes the "planned" and "unplanned" non-food use (animal feed, bioenergy, etc.) |
| Root causes of the loss or waste (Intention) | Natural | Behavioral or voluntary | Confusion can occur due to subjective perceptions of the meaning "behavioral" or "voluntary" in different contexts |

Some researchers have attempted to measure the quantity of food loss or waste without focusing on the distinctions between the definitions. For instance, Bellemare et al. (2017) define FLW as a simple measurement of the difference between the total volume of food production and the sum of food usage in any form. Likewise, the Food Policy Research Institute (2016) provides a new term, “Potential FLW”, which includes pre-harvest losses and unrealized possible losses.

The terminology we apply combines the definitions of HLPE (2014) and Quested and Johnson (2009) (see Figure 1). Regardless of the intention (natural or behavioral), which is difficult to measure, we consider whether the loss or waste could be avoided by OM at different stages of the FSC. Our approach holds that food loss refers to the quality and quantity decrease at upstreams of

FSC, from production to distribution; whereas, food waste involves a decrease at the consumption stage, including customer consumption and retail consumption (i.e., in restaurants or similar).

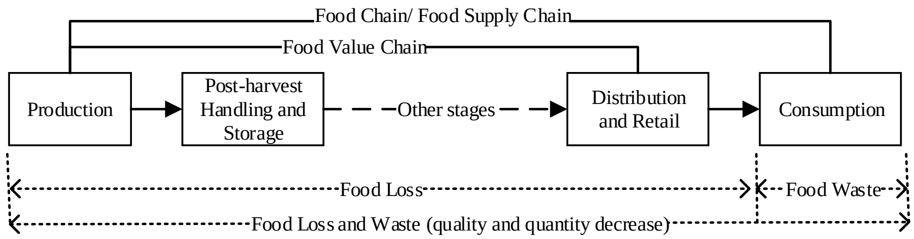


**Figure 1** Food loss and waste defined

## 3. Review methodology

### *3.1. Literature search*

We developed our literature review with an inductive approach, including existing literature on FLW in OM until December 2021. Because FLW research can be found in multiple disciplines, such as agricultural and biological sciences, environmental science, chemistry, and engineering, and to limit our search to the OM field, as the first step, we defined two key sources for the articles: prestigious OM journals and other related journals adopting OM methods.

For OM-journal selection, we selected 66 journals (see Appendix 2) from the "University of Texas at Dallas 24 Journals", "Financial Times' Journals list", "ABDC Journal list" (ranking A*, A, and B journals), and "AJG Journal list" (ranking 4*, 4, 3 journals). For other related-jounal selection, we added 9 general management journals (e.g., *MIT Sloan Management Review*), and 13 prominent journals associated with FLW reduction in economic, environmental, and food science (e.g., *Journal of Cleaner Production*). We used the Scopus, Springer Link, and EBSCOhost Academic Search Premier databases to search for the manuscripts. In addition, we asked for suggestions from a group of prominent OM scholars in FLW research.

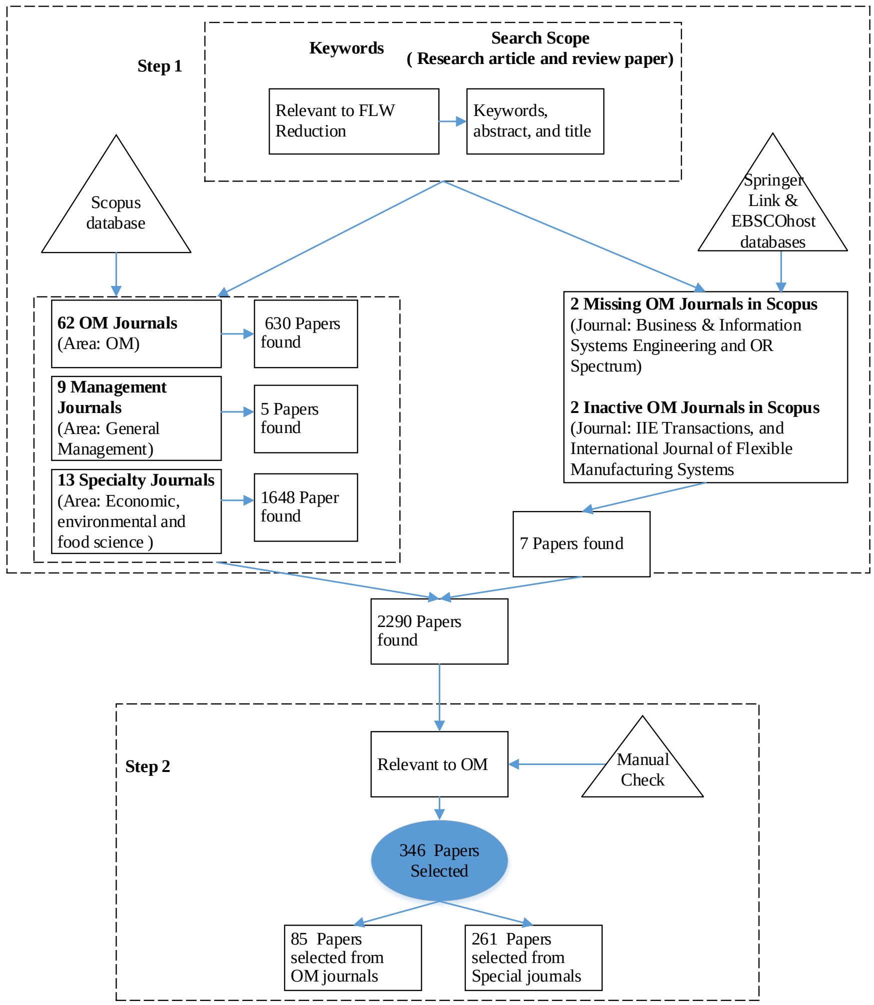


**Figure 2** Literature selection process

The keywords we used in our literature search are related to the concept of FLW itself. The search targeted publications titles, abstracts, and keywords. The search syntax used was "(loss OR waste OR wastage) AND (food OR post-harvest OR agribusiness OR durable OR perishable OR fresh OR shelf-time OR fruit OR vegetable OR meat OR fish OR dairy OR grain OR cereal OR oilcrop OR roots OR beef OR milk). The search syntax covered specific foods apart from general FLW. This stage found 2290 research papers. We read their abstracts to retain the papers within the OM field by judging their research contexts (food supply chain, food value chain, food system, food chain, food production, food distribution, or post-harvest loss). We also manually checked the sources referenced in each review paper and, from these, we created a list of papers within the OM field before eliminating the review papers. We eventually selected 346 research articles (see Appendix 3) in the final sample. The literature search steps are summarized in Figures 2.

### *3.2. Review procedures*

We follow the procedures outlined in Figure 3 to analyze the literature sample and to project future research directions. First, we conduct descriptive analysis to provide an overview of FLW research (Section 4). Second, we perform content analysis (Neuendorf, 2019) to examine research questions in the extant literature, and highlight the similarities and differences in two research perspectives, namely, the perspective of specific FSC stages vs the perspective of the entire FSC (Section 5). Third, we employ text mining (Song et al., 2020) to identify the overarching research themes (Section 6). This step also draws insights from clustering the research questions in the second step. Finally, we discuss future research directions drawing insights from the literature analyses as well as from presentations in the leading OM conferences, working papers, and 30 semi-structured interviews with a wide range of FSC stakeholders (Section 7).

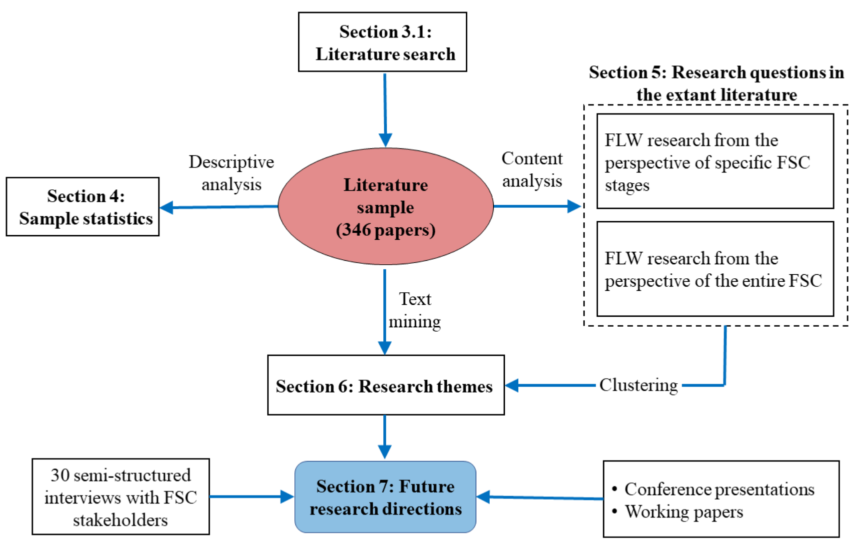


**Figure 3** A framework of review procedures

## 4. Sample statistics

Figure 4 plots the trend line for paper counts by year. Research studies on FLW were sporadic in the first decade of the 2000s. However, research attention started to pick up in the 2010s, with a sharp increase in publications being observed after the mid-2010s. This is likely due to the increasing concern on FLW across the globe in recent years.

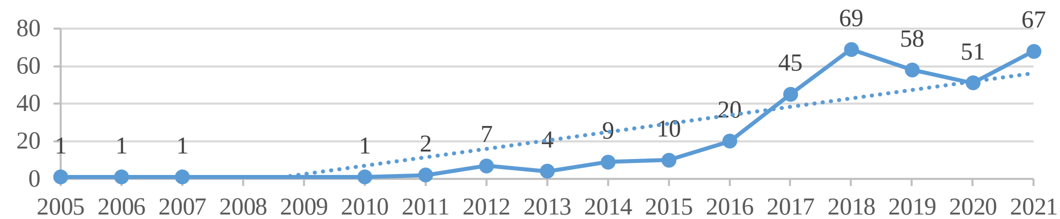


**Figure 4** Count of papers by year

Rather than being concentrated within a handful of journals, FLW studies in OM are published in a wide range of journals, as shown in Figure 5. *Journal of Cleaner Production* is the most popular outlet, publishing 132 papers in our sample. Three other speciality journals, *Waste Management*, *British Food Journal*, and *Food Policy*, are also very influential, publishing 58, 37 and 20 papers, respectively. Among the OM journals, *International Journal of Production Economics* (17 papers) plays a leading role, followed by *Transportation Research Part E: Logistics and Transportation Review* (11 papers), *Annals of Operations Research* (7 papers), *Computers and Industrial Engineering* (7 papers), *European Journal of Operational Research* (7 papers), and *International Journal of Production Research* (7 papers).

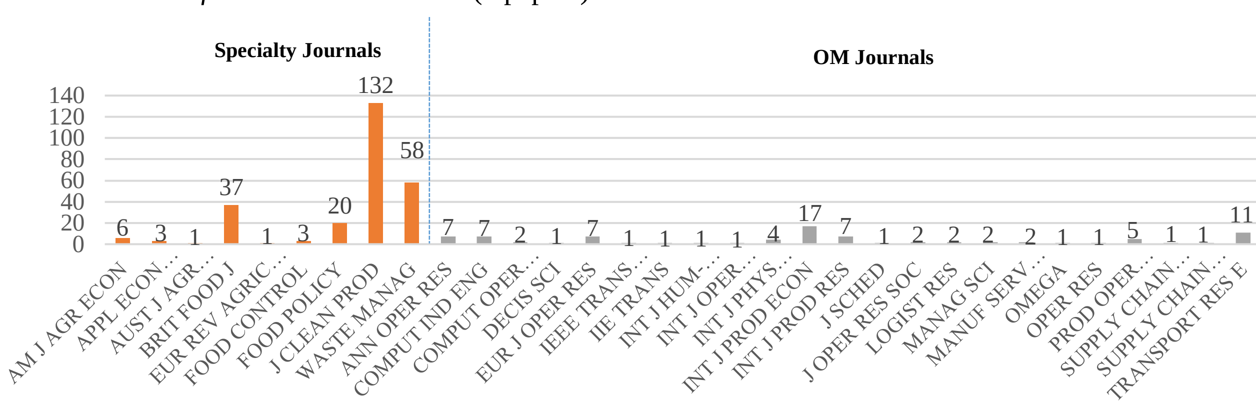

**Figure 5** Distribution of articles in our review pool

Extant FLW research employs a variety of methods. Figure 6 delineates the distribution of articles applying different methods; around 30% of studies employ qualitative methods to explore FLW problems. Heikkilä et al. (2016) suggest that, to explore and illustrate unstructured phenomena, qualitative research approaches are appropriate; although, Lee (2018) argues that there are limitations in the universality and applicability of results derived from qualitative methods. Statistical analysis and life-cycle assessment (LCA), which are mainly used for quantitative empirical research, account for 127 and 30 papers, respectively. The remaining 81 papers in the sample involve a variety of other quantitative methods, including multi-criteria decision making (MCDM) (8 papers), deterministic optimization (32 papers), simulation (14 papers), stochastic optimization (18 papers), game theory (7 papers), and robust optimization (2 papers). Overall, FLW studies in the OM field are dominated by empirical methods. More modeling works, which have a different nature from qualitative and quantitative empirical works, may be beneficial for generating new insights for reducing FLW.

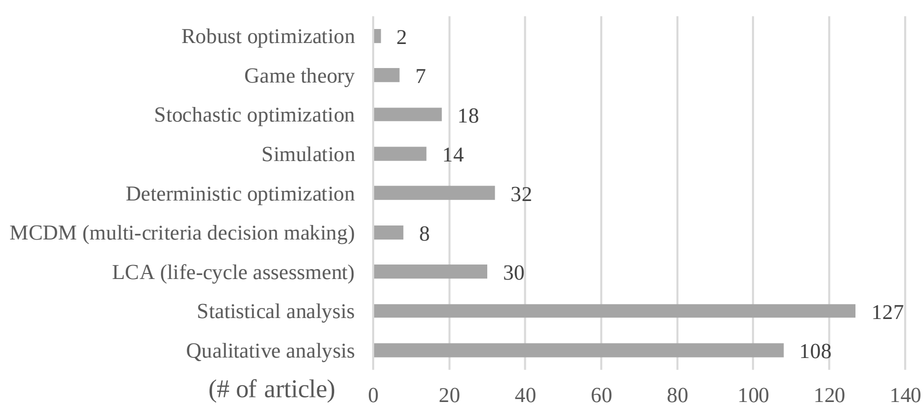


**Figure 6** The distribution of methods employed

## 5. Research questions in FLW studies

To provide an overview of the topics currently discussed in FLW studies, we perform content analysis (Neuendorf, 2019) to categorize the literature into two groups: the first group consists of studies from the lens of specific stages within the FSC and the second consists of studies from the perspective of the entire FSC. According to this classification, we listed the research questions that were examined in each group (see Tables 3 and 4), highlighting the specific research questions covered by each paper. This summary helps us understand the differences and similarities between the research questions in each FSC stage and along the entire chain.

**Table 3** Research questions in specific FSC stages

| Stage | Research Questions |
|---|---|
| Production | Q1. What are the causes of FLW?<br>Q2. What are the measures taken to reduce FLW and their performances?<br>Q3. How to define and quantify FLW.<br>Q4. How to prevent FLW.<br>Q5. How to optimize or design production planning with respect to FLW reduction.<br>Q6. What are farmers' attitudes towards FLW? |
| Post-harvest handling and storage | Q1. How to improve the performance of post-harvest operations.<br>Q2. What policies, strategies, approaches, or interventions can help to reduce FLW?<br>Q3. How to balance the costs and benefits of FLW reduction. |
| Processing | Q1. What are the causes of FLW generation?<br>Q2. What are the drivers and/or barriers of FLW?<br>Q3. What is the role of reuse and recycling in FLW reduction?<br>Q4. How to quantify or measure FLW.<br>Q5. What are the environmental, economic, and social impacts of FLW? |
| Distribution and retail | Q1. What is the impact of managerial attitudes and technical methods on FLW mitigation?<br>Q2. What policies, strategies, approaches, or interventions can help to reduce FLW?<br>Q3. What are the drivers and barriers of FLW reduction?<br>Q4. What is the relationship between the practices of FLW reduction, economic performance, and/or environmental benefits?<br>Q5. What is the link between innovation practices and FLW management?<br>Q6. What are the causes of FLW generation?<br>Q7. How to maximize the satisfaction of demand level considering the FLW control.<br>Q8. To what extent can inventory control reduce FLW in quantities and cost?<br>Q9. How to reduce FLW by optimizing/planning the logistic and/or distribution channel.<br>Q10. How to construct the distribution network to reduce FLW.<br>Q11. How does FLW management affect the efficiency of distribution?<br>Q12. What is the value of FLW?<br>Q13. What is the role of diverse distribution channels and their efficiency on FLW reduction?<br>Q14. How does replenishment policy impact the FLW reduction<br>Q15. What is the impact of the supply chain structure on retailers' performance considering waste reduction in FSC?<br>Q16. How to map and quantify FLW in retail trade. |

| | |
|---|---|
| Consumption | Q1. What are consumers' attitudes towards FLW?<br>Q2. What policies, strategies, approaches, or interventions can help to reduce FLW?<br>Q3. What are the factors affecting FLW behaviors?<br>Q4. How to quantify, classify or measure FLW.<br>Q5. How does FLW at the household level affect food security?<br>Q6. What are the impacts of consumers' or food purchasers' decisions on FLW?<br>Q7. What are the drivers and barriers of FLW reduction?<br>Q8. What are the causes of FLW generation?<br>Q9. What are the possible impacts of different methods on FLW generation?<br>Q10. What are the territorial differences of consumers' behavior toward FLW?<br>Q11. What are the economic and environmental impacts of FLW?<br>Q12. What are the costs and benefits of FLW reduction?<br>Q13. What methodologies can be used to deal with FLW and their performances?<br>Q14. What is the impact of COVID-19 on consumer food waste behavior? |

**Table 4** Research questions from the perspective of the entire FSC

| **Research Streams** | **Research Questions** |
|---|---|
| FSC sustainability | Q1. How does FLW reduction support sustainable policies?<br>Q2. How to manage the sustainability of FSCs by reducing FLW.<br>Q3. How to create a sustainable FSC by using and recovering FLW.<br>Q4. How to optimize a competitive FSC with sustainability consideration by reducing FLW.<br>Q5. How to transform to circular economy by reusing and reducing FLW. |
| FSC design | Q1. How to design the supply chain while maximizing profits and minimizing FLW.<br>Q2. How to design the logistical structure and close loops to reduce FLW.<br>Q3. How to design the FSC by integrating harvesting decisions.<br>Q4. How to design the FSC network to manage FLW.<br>Q5. How to optimize the configuration of FSC to reduce FLW.<br>Q6. How to build a green FSC by construcing a digitized FSC to reduce FLW. |
| FSC cooperation | Q1. How to reduce FLW through collaboration.<br>Q2. What is the effect of different types of collaboration on the level of FLW?<br>Q3. How to determine the replenishment schedule and dynamic prices considering FLW reduction during cooperation between the FSC stakeholders.<br>Q4. What are the optimal pricing, inventory and preservation decisions that help to reduce FLW?<br>Q5. What are the optimal sourcing strategies that help to reduce FLW?<br>Q6. What is the optimal pricing and ordering policy in the presence of contracts and FLW?<br>Q7. What are the impacts of integration on profits and FLW reduction performance?<br>Q8. What is the effect of contracts on shrinking inventories and FLW reduction? |
| FSC risk | Q1. How to evaluate the FSC risk and its implication for FLW reduction.<br>Q2. What is the impact of COVID-19 on food insecurity and FLW in the FSC? |
| FSC surplus-to-waste transition mechanism | Q1. How does overproduction contribute to FLW along the FSC? |
| FLW measurement | Q1. How to measure or quantify FLW in the entire FSC.<br>Q2. What is the value of FLW reduction in the entire FSC?<br>Q3. What is the quantity and quality of FLW along the FSC? |
| Environmental, economic, and social impact | Q1. How to quantify and assess the environmental impact of FLW.<br>Q2. What are the environmental, economic, and social impacts of FLW?<br>Q3. How to manage food security through FLW reduction.<br>Q4. How to use different management options to reduce the environmental, economic, and social impacts of FLW.<br>Q5. How to manage nutrient losses through FLW reduction. |
| Root causes of FLW | Q1. What are the critical factors and causes for FLW?<br>Q2. What are the challenges inhibiting FLW in the FSC?<br>Q3. How do different stakeholders prevent FLW while realizing the root causes of FLW? |
| Inventory management | Q1. How to manage the inventory to reduce quality degradation.<br>Q2. What are the mitigation strategies for expiration in emergency inventory system? |
| Impact of technologies or policies on FLW reduction | Q1. How are the technologies used to reduce FLW and their performances?<br>Q2. How do policies help to manage FLW. |

| | |
|---|---|
| Policy design and government intervention | Q1. What are the challenges for FLW polices?<br>Q2. How to design the policy for FLW prevention.<br>Q3. What is the role of FLW hierarchy?<br>Q4. How to evaluate FLW policies. |
| Suboptimal food products management | Q1. How to manage suboptimal food products to prevent FLW.<br>Q2. What is the environmental impact of cosmetic standards? |
| Recovery, Recycling and Redistribution | Q1. How to design a sustainable supply chain using the residues/FLW.<br>Q2. How does a donation/recycling/redistribution policy work and to what extent is it effective?<br>Q3. What are the drivers and barriers of recovery, recycling and redistribution?<br>Q4. How to use technologies/policy/other measures to reduce FLW.<br>Q5. What are the factors that impact donation/ recycling/ redistribution behaviors?<br>Q6. What are the benefits of recovery, recycling and redistribution programs?<br>Q7. What are the challenges or motivations of non-profit organizations in the operations of FLW reduction?<br>Q8. What are the values and environmental, economic, and social impacts of recovered, recycled, and redistributed products? |

Two hundred and forty-four papers were classified into different stages in the pool of 346 articles, among which around 60% of the articles center on the consumption stage. This finding concerning the OM literature is consistent with the trend across all fields (Filimonau and Gherbin, 2017) in which FLW studies predominantly focus on the consumption stage and on the downstream end of FSCs. To an extent, Table 3 concludes the  research questions reflecting the research focus in each stage, such as production planning in the production stage, reuse and recycle issues in the processing stage, logistics and distribution solutions in the distribution and retail stage, and analysis of consumer behavior in the consumption stage.

Rather than focusing on a specific stage, 102 papers deal with FLW issues from the perspective of the entire FSC. As indicated in Table 4, the focus of these papers ranges from supply chain design to cooperation to inventory management, etc. They reflect how OM researchers tend to approach and analyze FLW issues within FSCs.

Comparing the research questions in these two perspectives, we can see that both groups deal with FLW causes and measures, barriers and drivers to FLW reduction, economic impacts, management practices, and behavior aspects. However, studies from the perspective of the entire FSC are comparatively more interested in the triple bottom line (all three dimensions of sustainability, i.e., economic, environmental, and social), FSC cooperation and collaboration, technology adoption, value recovery from FLW, and government policy interventions. This is likely because these aspects require a more systematic treatment in research investigations, hence a holistic supply chain perspective is more suitable than a functional perspective.

## 6. Research themes

As shown in Section 5, FLW topics are scattered across multiple areas. Even when studies are grouped into different stages of the FSC, topics may overlap despite focusing on different stakeholders. This creates difficulties in the comparative analysis of relevant studies. Organizing these papers into different research themes is one way of navigating the body of FLW literature. In this section, we discuss the research themes identified from our literature review.

### *6.1. Identified research themes*

We employed a text mining method to search and identify a particular set of research themes in the literature we reviewed. Although text mining has its limitations, this method is regarded as an efficient way of selecting papers, and providing a brief overview of the research streams that emerge (Song et al., 2020). Table 5 describes the initial codes and the show rate.

**Table 5** The identified research themes from text mining

| Abstracts or keywords containing | Number of papers | Percentage as a fraction of all papers* | Possible Research Themes |
|---|---|---|---|
| Consumer behavior | 56 | **16%** | √ |
| Consumer awareness/preference/attitude/acceptance/decision/intention/engagement/choice | 29 | 8% | |
| Composition | 13 | 4% | |
| Environmental studies (including carbon emissions, carbon footprint, greenhouse gas emissions, climate impact, environmental impacts/concerns/evaluation/effects) | 46 | **13%** | √ |
| Economic incentive/monetary value/cost analysis/value degradation | 20 | 6% | |
| FSC, food value chain, food systems, food chain | 88 | **25%** | √ |
| FSC cooperation/contract management | 15 | 4% | |
| FSC information sharing, risk management, design, disruption management | 11 | 3% | |
| Measurement/quantification | 41 | **12%** | √ |
| Methodologies (including qualitative research, life cycle assessment, linear programming, robust optimization, mixed-linear integer programming, game theory, simulation, action research, multi-objective optimization, multi-objective programming, SEM, material flow analysis, DEMATEL, stochastic optimization, practice theory, exploratory analysis, experimental analysis) | 99 | **29%** | √ |
| Macro-level policy (including food waste hierarchy analysis, food security, food safety, circular economy, sharing economy, closed-loop supply chain) | 38 | **11%** | √ |
| Operations-based policy and strategy (including dynamic pricing policy, capacity planning, sourcing strategy, nudge, optimal ordering policy, menu planning, replenishment policy, discount policy, reduction strategies, technology investment decisions, food labels management, shelf life management, expiration management, lean management, sales forecasting, harvesting patterns, education) | 61 | **18%** | √ |

| | | | |
|---|---|---|---|
| Operations-based activities analysis (including inventory, delivery, logistics, distribution, transportation, storage, production, procurement, retail operations, vehicle routing, packaging, process, resource allocation) | 81 | **23%** | √ |
| Root cause analysis | 49 | **14%** | √ |
| Recycle, reuse, recovery, donation, by-product, reverse logistics | 27 | 8% | |
| Sustainability (including sustainable development, sustainable consumption, sustainable management, sustainable operations management) | 61 | **18%** | √ |
| Technology (including technological innovation, technology investment, internet of things, intelligent container, digitization, forecasting technology, intelligent packaging, cold chain, blockchain) | 20 | 6% | |
| Uncertainty analysis (yield uncertainty, dynamic expiry date, food and labor supplies, demand) | 17 | 5% | |

* The BOLD percentage is highlighting the result that is greater 10%, which we consider as an important cluster.

Applying the QDA Miner Lite software, we constructed research themes in six steps. The steps were designed by following the works of Song et al. (2020), Wassmer (2010), and Duriau et al. (2007). First, we imported the abstracts of selected papers, and 1,039 keywords were distilled and marked in the software system. Then, we excluded the ones that are not applied in our coding process, for example, “literature review”, “descriptive research”, and “case study”. This left us with 670 keywords to guide our text mining process. Third, we created initial codes in the software (summarized in Table 5). Next, we highlighted the important clusters with the criterion that a cluster is selected when the percentage as a fraction of all papers is greater than 10%. In the fifth step, using hierarchical method, we adjusted our coding framework by referring to the literature (HLPE, 2014), which classified FLW research from macro, meso, and micro levels, and setting up the subsections according to Tables 3 and 4 exploration. Finally, we classified the clusters into research themes (see Figure 7).

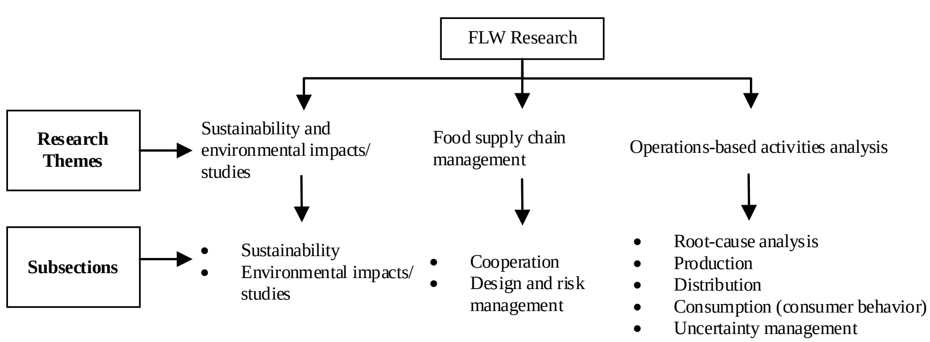


**Figure 7** The structure of the research themes*

* Some FLW studies may cover multiple research themes.

### 6.2. *Sustainability and environmental impacts/studies*

One hundred and eleven papers (almost one-third of our selected papers) contain "sustainability" or "environmental impacts/studies" in the keywords list or the abstract, of which 76 are dedicated to sustainability and environmental research.

#### 6.2.1. *Sustainability*

Within FLW and sustainability, key topics include sustainable development (e.g., Liu et al., 2018, Derqui et al., 2020), sustainable consumption (e.g., Coderoni and Perito, 2020), sustainable supply chain management (SCM) (e.g., Liu et al., 2021), and sustainable OM (e.g., Garcia-Herrero et al., 2018). These studies involve the investigation of FLW reduction activities using a general operations management lens, exploring aspects such as residual recovery, consumer packaged goods management, sustainable production management, and sustainable business models. Three methodologies are predominantly applied: life cycle assessment, qualitative analysis, and statistical analysis For example, using life cycle assessment, Salemdeeb et al. (2017a) demonstrate a sustainable business model that includes an environmental matrix. Lam et al. (2018) construct a sustainable FLW management method for the international airport in Hong Kong. Employing a qualitative analysis method, Sgarbossa and Russo (2017) construct a proactive model in a sustainable FSC. Applying statistical analysis, Garcia-Herrero et al. (2018) discuss how to support sustainable production by reducing potential food waste.

Rather than concentrating on each FSC stage, sustainability analysis in FLW research primarily adopts an integrated supply chain perspective. Distinct from general SCM, the studies approach their respective challenges by considering FLW minimization or the evaluation of FLW (e.g., Kaipia et al., 2013, Garcia-Herrero et al., 2018).

#### 6.2.2. *Environmental impacts/studies*

Fifty-seven papers consider how to quantify the environmental impact of FLW, of which, 30 papers apply life cycle assessment to evaluate this impact from a country or district level, including Switzerland (Willersinn et al., 2017), the United Kingdom (Tonini et al., 2018), Norway (Svanes and Johnsen, 2019), Turkey (Cakar et al., 2020), and Europe (Scherhaufer et al., 2018), and from specialized processes in FSCs, such as packing (e.g., Wikström et al., 2016), animal feed (e.g., Salemdeeb et al., 2017b), processing (Li et al., 2020), consumption (García-Herrero et al., 2019, 2021), resource recovery (Krishnan et al., 2020), and surplus food redistribution (Damiani et al., 2021). Sixteen papers employ qualitative or statistical analysis methods to assess the environmental impact of FLW, from which FLW management options are variously linked to the waste hierarchy (e.g., Eriksson et al., 2015), the circular economy (e.g., Coderoni and Perito, 2020), and closed-loop supply chains (e.g., Sgarbossa and Russo, 2017). Ten papers consider environmental impact as one of the constraints or variables in a multi-objective optimization approach, using deterministic optimization (e.g., Cattaneo et al., 2021), stochastic optimization (e.g., Belavina et al., 2017), and simulation (e.g., Kuiper and Cui, 2021). One paper applies multi- criteria decision making (MCDM) to evaluate the environmental impact of food waste (Plazzotta et al., 2020).

Studies within these streams often assume that FLW reduction has a positive impact on environmental improvement, and much literature follows this logic. However, the European Commission report in 2006 suggests that, to assess all the environmental benefits of FLW reduction initiatives, two issues should be considered: whether FLW has been actually reduced, and whether efforts at reducing FLW negatively affect downstream stages of the life cycle. For instance, using refrigerated facilities during transportation help to reduce FLW but increase the carbon footprint.

### *6.3. FSC management*

One hundred and fifty-two papers contain FSC, value chain, food systems, and food chain in their keywords or abstract, of which 102 papers investigate FLW issues from the entire FSC. The topics within this field are various, including information sharing (e.g., Kaipia et al., 2013), risk management (e.g., Ali et al., 2019), supply chain design (e.g., An and Ouyang, 2016; Jonkman et al., 2018; Song et al., 2021) and cooperation (e.g., Wang and Chen, 2017), and supply chain resiience in the Covid-19 context (Burgos and Ivanov, 2021). The following subsections focus on measures to reduce FLW in reviewing the most relevant publications.

### *6.3.1. FSC cooperation*

The FAO (2011) highlights that improvements in cooperation between stakeholders in a supply chain can positively impact FLW reduction. An appropriate coordination mechanism can encourage stakeholders to reduce FLW and optimize FLW management (Halloran et al., 2014). Ideally, appropriate cooperation leads to optimal ordering from the retailer, strategic pricing from the supplier, and/or astute investment to increase preservation. However, even though cooperation is a topic often examined by OM researchers, FSC cooperation studies in FLW reduction contexts remain scant.

Game theory is an approach often applied by researchers in a bid to solve cooperation problems in FLW reduction. Within this approach, FLW performance is usually presented as a parameter or constraint (e.g., Yu et al., 2020). For example, Huang et al. (2018) developed a Stackelberg game model aiming to maximize individual profits. This study included a FLW factor by considering an investment in preservation, which reduces the deterioration rate and carbon emissions.

Qualitative approaches in cooperation research provide a lens to examine the FLW situation in practice and offer a theoretical basis for in-depth research. For instance, innovative collaboration between stakeholders is considered by practitioners to have positive effects on FLW reduction (Martin-Rios et al., 2018). Cooperation can come in the form of improvements to, or the creation of, interorganizational relationships through information exchange, incentive engagement, and technology sharing (Bustos and Moors, 2018). Exploratory research of this nature offers insights into how stakeholders interact with each other and engage in FLW reduction activities.

### *6.3.2. FSC design and risk management*

Studies involving FSC design that take into consideration FLW tend to include decisions on processing and storage facilities investment and pricing policies (e.g., An and Ouyang, 2016), logistical structure (e.g., Banasik et al., 2017), harvest timing (Jonkman et al., 2018), and interorganizational coordination (Ghinoi et al., 2020). These decisions usually consider FSC interruptions and risk management, including short and long-term risks.

Short-term risks can be anticipated and evaluated, such as lack of storage facilities, non-cooperative farmers in harvesting, and inferior technologies. Long-term risks might be mitigated by planning, monitoring, outsourcing, and controlling the FSC (Ali et al., 2019). Consideration of risk management within FLW research remains scant in this body of literature.

Within the FSC design literature, a subset of research has investigated how to reduce FLW by an appropriate design of value-added processes, pricing policies, or through improved technology. Table 6 summarizes the literature in this area.

**Table 6** Measures to reduce FLW by process and supply chain design

| Reference | Methodology | Measures to reduce FLW |
|---|---|---|
| (Ahumada and Villalobos, 2011) | Deterministic optimization | Planning design |
| (An and Ouyang, 2016) | Robust optimization | Processing/storage facilities investment and pricing policy design |
| (Brulard et al., 2019) | Deterministic optimization | Farming system design |
| (Beullens and Ghiami, 2021) | Deterministic optimization | FSC structure design |
| (Despoudi et al., 2018) | Statistical analysis | Collaboration |
| (Fikar, 2018) | Simulation | Inventory and delivery strategy design |
| (Hafliðason et al., 2012) | Statistical analysis | Temperature control |
| (Herbon and Khmelnitsky, 2017) | Stochastic optimization | Dynamic pricing and replenishment policy design |
| (Jonkman et al., 2018) | Stochastic optimization | Supply chain design |
| (Janssen et al., 2018) | Stochastic optimization | Inventory replenishment policy design |
| (Liljestrand, 2017) | Qualitative analysis | Logistics solutions |
| (Mogale et al., 2017a,b) | Deterministic optimization | Transportation and storage design |
| (Mogale et al. 2018) | Deterministic optimization | FSC network desgin |
| (Maiyar and Thakkar, 2019) | Deterministic optimization | Logistics planning |
| (Christensen et al., 2021) | Qualitative analysis | Forecasting accuracy |
| (Orgut et al., 2016) | Deterministic optimization | Distribution design for food donation |
| (Reddy et al., 2017) | Simulation | Procurement optimization, Routing design |
| (Rey et al., 2018) | Deterministic optimization | Food rescue pickup and delivery logistics design |
| (Rijpkema et al., 2014) | Qualitative analysis | Sourcing strategy |
| (Sheppard et al., 2020) | Qualitative analysis | Decision-support infrastructure design |
| (Song et al., 2021) | Deterministic optimization | Omni-channel strategies |
| (Wang and Chen, 2017) | Stochastic optimization | Pricing policy design and coordination |
| (Widodo et al., 2006) | Deterministic optimization | Delivery design |

*6.4. Operations-based activities analysis*

Two hundred and forty-four papers discuss FLW issues in different stages of the FSC and focus on operations-based activities. A wealth of topics is discussed and covered, especially at the distribution and retail stage (65 papers) and consumption stage (159 papers). To provide an overview of FLW occurrence causes in each stage, we first examine the root cause of FLW generation. Following this analysis, we discuss the research themes identified in the distribution and consumption stages and analyze the uncertainty problems occuring in all the stages.

**Table 7** Root-cause analysis

| **Stage** | **Key words** | | **Methodology** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Causes | Details | Stochastic Optimization | Statistical analysis | Qualitative analysis | Game Theory | Deterministic optimization | Simulation |
| Production | Context characteristics, logistical operations, quality control | Storage facility, market price, infrastructure, overproduction | | √ | √ | | | |
| Post-harvest handling and storage | Operations strategy | Operating policy, policy efficiency, refrigeration shortage, careless handling, exceeding volume in purchases | √ | | √ | | | |
| Processing | Logistical operations, quality control, consumer demand | Equipment defects, human errors, experimental losses, cleaning losses, blackout, package deformation, recipient rejection, customer demand change | | | √ | | | |
| Distribution and Retail | Managerial attitudes and approaches | Functionalized packing/packaging strategy, redistribution, market channel, delivery scheduling, technology investment, replenishment policy | √ | | √ | | √ | √ |
| Consumption | Regulation, customers' behavior, awareness and attitude, culture, product characteristics, marketing and sale strategy, technologies | Mandatory regulations, supervision, economic incentives, education, environmental awareness, income, eating / buying/ shopping/ storage behavior, religious belief, information, product shelf life, household size | | √ | √ | | | |
| Entire FSC | Coordination, government intervention, sustainability, cosmetic specifications, infrastructure, facility, pricing and inventory decisions, management practices | Knowledge and information sharing, long-term solution monitoring, contract breach, trust and loyalty, feasible intervention, sustainable resolution, food characteristics, supply chain uncertainty, market infrastructure, food policy and regulation, partnerships, networks, operational capability, quality management, process control, forecasting | √ | √ | √ | √ | | |

*6.4.1. Root-cause analysis*

FLW can occur at any tier of a FSC (Östergren et al., 2014). To investigate the mechanism of FLW generation, OM researchers apply different methodologies to identify and discuss the causes of FLW. Table 7 summarizes the causes identified by researchers at either each stage or from the entire FSC perspective.

We observe that 68% of the papers apply qualitative or statistical analysis to explore the key causes of FLW. The employed empirical research methods enable researchers to gather information in practice and explore the root causes of FLW generation. For example, Macheka et al. (2018) examine the possible determinants of FLW generation and identify that context characteristics, logistics operations, and quality management are the leading causes of observed FLW.

*6.4.2. Production*

FLW research focusing on the production stage remains scarce. Only 18 papers fell into this category from our selected pool, of which 15 papers usequalitative analysis, statistical analysis , and life cycle assessment to investigate FLW issues at the production stage. The topics for this stage involve FLW measurement (e.g., Ambler et al., 2018), product expiration reduction (e.g., Akkas and Sahoo, 2020), farmers' behavior (e.g., Bonadonna et al., 2019), farming system design (e.g., Brulard et al., 2019), overproduction (e.g., Darlington and Rahimifard, 2007), and approaches to FLW reduction (e.g., Thamagasorn and Pharino, 2019). We only found three papers that apply deterministic optimization to discuss FLW issues, all of which apply deterministic optimization. Figure 8 describes how this small analytic stream discusses FLW issues at the production stage.

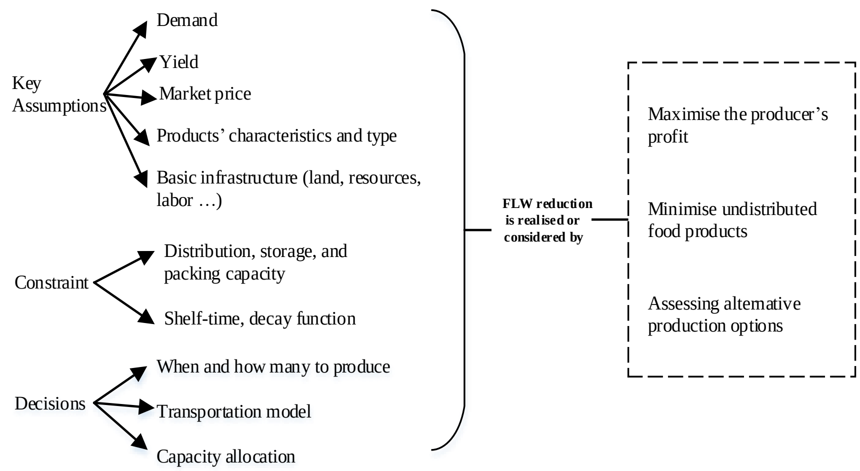


**Figure 8** Studies applying deterministic optimization at the production stage

*6.4.3. Distribution*

Distribution problems are significant issues in FLW reduction research. In an FSC context, they are investigated along three main aspects: maximizing the distribution amount (e.g., Orgut et al., 2016), distribution planning (e.g., Ahumada and Villalobos, 2011), and optimization of the distribution channel and network (e.g., Mogale et al., 2019; Chaboud and Moustier, 2021). FLW reduction might be realized by reducing the circulation loss during the distribution (e.g., Mangla et al., 2019), redistribution of the surplus or donated food (e.g., Garrone et al., 2016), and optimal distribution planning incorporating quality degradation (e.g., Ahumada and Villalobos, 2011).

Some studies focus on FLW problems without specific attention to the different distribution channels (e.g., Irani et al., 2018). In contrast, other studies address FLW differences between various forms of distribution channels, for instance, online retailing and physical retailing, or different stakeholders and value-added processes in the distribution channels. Even in the same food industry, the stakeholders or the processes involved may be different, leading to varying results in FLW research, including FLW measurement, environmental evaluation, and FLW causes. Table 8 summarizes the main topics that emerged from the work on distribution channels.

**Table 8** Topics identified in studies on distribution channels

| Reference | FSC stages or Actors | Objective | Methodology |
|---|---|---|---|
| Corrado et al. (2017) | Production, transport and storage, processing, distribution, consumption | Environmental evaluation | Life cycle assessment |
| Lütke Entrup et al. (2005) | Raw milk preparation, fermentation, flavoring and packaging, storage and delivery | Maximization of the contribution margin | Deterministic optimization |
| Halloran et al. (2014) | Primary sector, food processor, wholesaler and retailer, consumer and households, FLW processors | Analysis of FLW issues in Denmark | Qualitative analysis |
| Kaipia et al. (2013) | Milk supplier, logistics service provider, wholesaler, retailer | Creation of a sustainable model of closed-loop supply chain | Qualitative analysis |
| Macheka et al. (2017) | Harvesting, processing, storage, distribution | Exploration of logistics and quality control | Qualitative analysis |
| Mogale et al. (2017a) | Procurement, transportation, distribution, sales | Minimization of transportation, storage and operational costs of the food chain | Deterministic optimization |
| Mogale et al. (2019) | Farmers, procurement centers, central warehouse, state warehouse, district warehouse, fair price shops | Minimization of operations-based activities cost and carbon dioxide emission | Deterministic optimization |
| Redlingshöfer et al. (2017) | Production, harvest, storage, transport, processing, distribution, consumption, import/export | FLW quantification | Qualitative analysis |
| Salemdeeb at al. (2017a,b) | Collection, transportation, anaerobic digestion, import | Environmental evaluation | Life cycle assessment |
| Scherhaufer et al. (2018) | Production, food processing, retail distribution, consumption, food disposal | Environmental evaluation | Life cycle assessment |
| Sgarbossa and Russo (2017) | Farmer/livestock, production, distribution, sales | Creation of a sustainable model of closed-loop supply chains | Qualitative analysis |
| Song et al. (2021) | Retailer, consumers. | Discussion on Omni-channel strategies | Deterministic optimization |
| Tonini et al. (2018) | Farming, processing, wholesale and retail, food waste | Environmental evaluation | Life cycle assessment |
| Tostivint et al. (2017) | Milk supplier, collection points, factories, distribution and retail | FLW measurement | Qualitative analysis |
| Wesana et al. (2018) | Famer cooperative, processor, wholesaler, retailer | Exploration of actor readiness to reduce FLW | Statistical analysis |
| Widodo et al. (2006) | Farmer, retailer, consumer | Maximization of the demand level satisfied | Deterministic optimization |
| Willersinn et al. (2017) | Production, wholesaler, retailer, household | Environmental evaluation | Life cycle assessment |

### *6.4.4. Consumer behavior analysis*

FLW issues at the consumption stage have been widely investigated, and our search yielded 143 papers focusing on this stage. The topic of consumer behavior was highly dominant, and it is seen as one of the critical issues driving the FLW problem in developed countries (Jagau and Vyrastekova, 2017) while also attracting increasing scholarly attention in the context of developing countries (Song et al., 2018). Consumer behavior involves a range of dimensions, including emotions, eating and shopping habits, values, and beliefs, all of which can affect initiatives for FLW reduction. At a societal level, factors such as social norms, culture, policies, regulations, retailing sales strategies, or education can impact consumer behavior. A summary of topics in consumer behavior studies has been provided in the appendix 4.

*6.4.5. Uncertainty management*

Uncertainties in the problem settings of the FSC seem to need more attention in OM applications (Soto-Silva et al., 2016; Sgarbossa and Russo, 2017). In FLW studies, stochastic programming and robust optimization approaches are often used to capture the uncertainties in the objective function and/or constraints; 20 papers in our pool employ these methods to solve uncertainty problems.

Yield uncertainty is discussed as a key factor in FLW at the production stage. An and Ouyang (2016) present a robust optimization model with an objective of maximizing the company's profit and minimizing FLW. To deal with uncertainty, they assume that stochastic yield varies within a pre-determined uncertainty set. They construct a three-echelon supply chain network applying game theory under the decisions of distribution cost and marketing equilibrium.

Deterministic demand and unlimited product shelf-life are two traditional assumptions that are widely used in distributional design (Muriana, 2015). To relax the assumption related to deterministic demand, Soysal et al. (2015) propose an optimization model for inventory routing, with the objective of minimizing the costs of routing, inventory, and FLW. They employ a deterministic approximation of the chance-constrained programming model to solve the uncertainty in demand. To fill the gap related to unlimited shelf-life, Muriana (2015) constructs a stochastic optimization model under shelf-life uncertainty to examine the effectiveness of food recovery, while assuming demand is deterministic.

Price uncertainty describes the practical situation where the prices of food products may fluctuate, directly impacting both the profit of the entire FSC and actions taken to reduce FLW. Zhang and Jiang (2017) propose a robust mixed-integer linear programming model to solve FLW problems under uncertain prices. Process uncertainty is another issue affecting FLW reduction. Variations in temperatures during transportation and storage mean that the deterioration process is variable and uncertain.

Uncertainty and variability are applied interchangeably in some papers (e.g., Muriana, 2015); however, a group of researchers highlights the discrepancy between these two definitions, especially in life cycle assessment studies (Menna et al., 2018) and consider variability as an inherent characteristic in FSCs caused by human-made, internal, or operational mistakes that are controllable, and uncertainty as an external factor that cannot be controlled.

Rather than modeling the uncertainty, researchers often treat the variabilities as parameters of their models to solve FLW issues. For example, Corrado et al. (2017) indicate that the categories of avoidable, possibly avoidable, and unavoidable need to be considered as a parameter in FLW analysis. Lam et al. (2018) include transportation distance as a variable in their life cycle assessment study. Soto-Silva et al. (2016) recommend that OM researchers put more effort into considering "uncertainty".

## 7. Future research directions

Although the FLW literature has covered a range of topics and issues, we have identified that many research gaps remain. We have developed future research ideas based on four sources: our literature sample of 346 journal papers, presentations in the leading OM conferences, working papers, and the interviews we conducted with different stakeholders in the FSCs. As mentioned earlier, this research adopted a relevance-driven literature review approach to identify the problems and needs in practice. The development of future research directions was informed by insights from empirical data. Specifically, we employed a purposeful sampling approach to recruit interviewees who were knowledgeable on FLW issues to ensure the validity of the obtained practical insights. A diverse range of involved stakeholders (see Figure 9) helped us acquire a holistic and comprehensive understanding of FLW issues. We interviewed 11 large-scale enterprises (annual revenue > 5 million RMB), seven medium-scale enterprises (annual revenue 1-5 million RMB), and six small-scale enterprises (annual revenue < 1 million RMB). We also interviewed three associate directors from the governments and three experts from the NGOs to understand their perspectives on FLW reduction. In total, we conducted 30 semi-structured interviews. The profile of the interviewees is provided in Appendix 1. All the interviews were conducted online due to the COVID-19 pandemic in 2020. Interviews lasted between 30 and 60 minutes and the average interview duration was around 40 minutes.

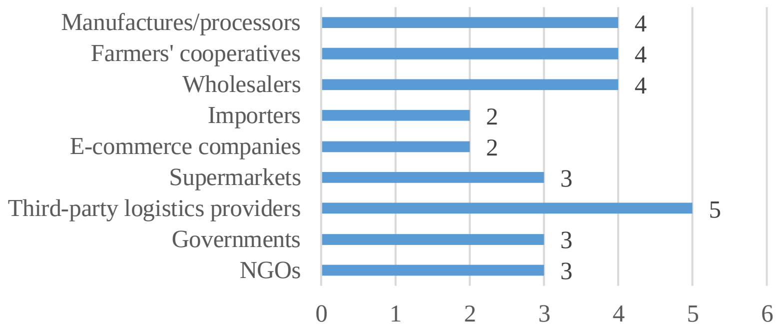


**Figure 9** Distribution of the interviewees

Table 9 presents a brief summary of the interview findings from all stakeholder groups. Apparently, different stakeholders have varying practical needs depending on the nature of their operations. For example, farmers' cooperatives are concerned about farmer behavior analysis, while supermarkets are keen to explore distribution channel optimization and consumer behavior analysis. Having said that, some stakeholders share similar practical needs. Notably, government intervention, technology application, and FSC cooperation are the three top areas. Around 50% of the interviewees mentioned these areas.

**Table 9** Summary of interview findings

| | **Interviewee designations** | **Practical needs for research** |
|---|---|---|
| Manufacturers/Processors | Manager (3)<br>Senior Supervisor (1) | Closed-loop and circular SCM, FSC cooperation, demand forecasting, new technology adoption, and risk management |
| Farmers' cooperatives | Head of Cooperative (3)<br>Vice President (1) | Government intervention, demand forecasting, farmer behavior analysis, FSC cooperation, Agri 4.0 application, and new technology adoption. |
| Wholesalers | Vice President (1)<br>General Manager (1)<br>Manager (2) | FSC cooperation, new technology adoption, facility investment, and government intervention |

| | | |
|---|---|---|
| Importers | General Manager (2) | New technology adoption, FSC cooperation, distribution system optimization, and government intervention |
| E-commerce companies | Vice President (1)<br>General Manager (1) | FSC cooperation, new technology adoption, and government intervention |
| Supermarkets | Head (1)<br>Customer Service Manager (1)<br>Operations Manager (1) | FSC cooperation, demand forecasting, risk management, new technology adoption, distribution channel optimization, consumer behavior analysis, pricing strategy |
| Third-party logistics providers | Customer Service Manager (1)<br>Vice President (2)<br>Department Director (1)<br>Operations Manager (1) | Customer cooperation for packaging recycling, new technology adoption, distribution optimization, government intervention, and process optimization |
| Governments | Associate Director (3) | The implementation of Anti-food Waste Law, the effectiveness of government intervention, performance of new technologies, and effective approaches for assisting SMEs |
| NGOs | Director (1)<br>SCM expert (1)<br>Head (1) | Distribution network optimization, new technology application, government interventions, food donation, and the roles of NGOs |

Figure 10 provides an overview of the prominent research gaps and how they were derived from the insights from the four sources as mentioned above. Collectively, significant research opportunities exist for OM researchers in FLW reduction. In the following subsections, we discuss the most important research directions.

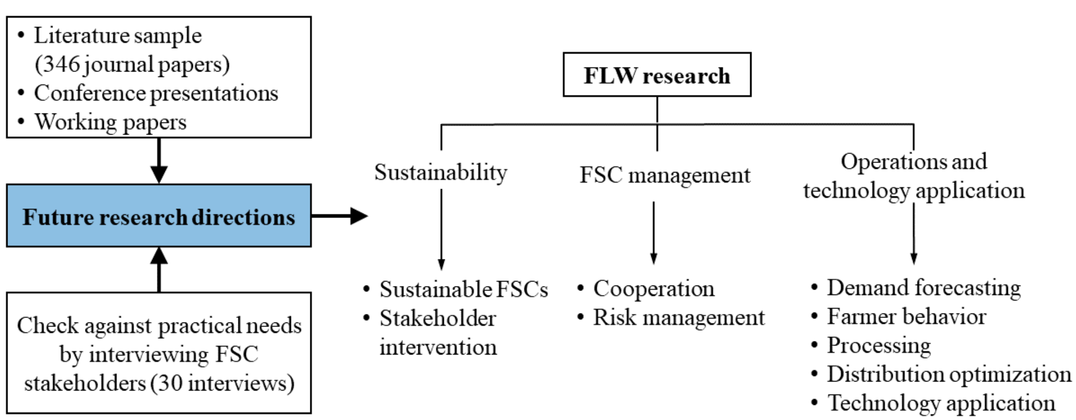


**Figure 10.** Future directions for FLW research

### *7.1. Sustainability*

#### *7.1.1. Sustainable FSCs*

A sustainable FSC, green supply chain, or closed-loop supply chain represents a potential solution to realizing sustainable operations (Sgarbossa and Russo, 2017; Ala-Harja and Helo, 2014). In recent years, circular food supply chain has been advocated for transitioning to a circular economy (Farooque et al., 2019a). Circular supply chain is a multi-dimensional concept which encompasses closed-loop supply chain, reverse supply chain, remanufacturing supply chain, industrial symbiosis, among others (Zhang et al., 2021). In comparison with closed-loop SCM, circular SCM can further advance resource circularity because it enables value recovery from waste not only in the original supply chain but also in other supply chains (Farooque et al., 2019b; Zhang et al., 2021).

To some extent, the performance of FLW reduction in a sustainable FSC reflects the social responsibility of the stakeholders involved (Filimonau and Gherbin, 2017). Success in FLW reduction may positively affect stakeholders' reputations and create potential market value for the whole supply chain (Sgarbossa and Russo, 2017; Mangla et al., 2021). FLW prevention encourages stakeholders to cooperate, seek solutions, and create close connections with each other in a sustainable FSC.

Studies that offer models for a sustainable FSC are currently limited in number. What studies that do exist include a multi-objective optimization of sustainable FSCs (Zhang and Jiang, 2017), a model of the distribution system in the context of sustainable FSCs using a bi-objective approach (minimizing costs and carbon dioxide emissions simultaneously) (Mogale et al., 2019), creating a sustainable FSC through information sharing or closed-loop supply chain development (Kaipia et al., 2013; Sgarbossa and Russo, 2017), and sustainable FSC management for perishable food (Liu et al., 2021).

Research on traditional closed-loop supply chains often focuses on the durable goods industry, and few quantitative modeling approaches exist which apply closed-loop supply chains in the FSC (Banasik et al., 2017b). In the emerging circular SCM domain, research attention is also lacking in the agri-food sector (Zhang et al., 2021).

### *7.1.2. Stakeholder intervention*

Typical sustainability studies encompass three-dimensional (environmental, social, and economic) or four-dimensional (environmental, social, economic, and technical) impacts. The predominant focus on the environmental impact of FLW has meant that consideration of other dimensions remains limited. A vice president at a small vegetable cooperative interviewed by us stated that "FLW reduction is important for us, as it contributes to environmental friendship and may improve our revenue"; however, "We do not have the financial capacity to invest in advanced package and pre-cooling facilities", and "we do hope to get help from OM researchers, especially on the topic of government intervention". The insights from industry reveal that many SMEs lack financial resources to invest in FLW initiatives and they would welcome positive government interventions. Thus, governments do have an interest to support businesses, especially SMEs. However, they usually do not have scientific data on the effectiveness of possible policy measures. OM researchers may well bridge the gap between the governments and businesses by conducting research on government interventions.

As previously mentioned, researchers often posit that FLW reduction has a positive influence on the environment and society. However, this contention is not as straightforward as it may appear and warrants more careful investigation. For instance, while FLW reduction may be a mechanism for alleviating hunger and improving the availability of food products, the occurrence of FLW may not match the location of those who are most affected by it. For example, the proportion of FLW in edible food is comparatively high at the consumption stage in developed countries where people can generally access food and a reduction of FLW here will not necessarily translate to an improvement in the health outcomes of this population. This raises questions, such as the possible roles of corporations, NGOs, and non-profit organizations in helping to construct sustainable FSCs and what interventions could be implemented to redistribute the sources converted from FLW into consumable products. A handful of studies have started to consider issues around social supermarket operations (Holweg et al., 2010), donation management (Buisman et al., 2019), and FLW conversion into by-products (Lee and Tongarlak, 2017; Chávez et al., 2018). However, more FLW research on stakeholder interventions for sustainability remains a pressing need.

An associate director in the Chinese government stated in our interview that "In the context of COVID-19, almost all countries are encountering the challenge of food security. FLW reduction is a possibly solution to relieve this situation". The state of food insecurity globally and the significant challenges arising from the COVID-19 pandemic are pushing society and firms to seek sustainable solutions to mitigate the food crisis (FAO, 2021, Burgos and Ivanov, 2021). Stakeholders in multiple tiers of the FSC are starting to realize the importance of food and agricultural resources, which may encourage them to consider more intervention measures for moving forward to a more sustainable business model.

A range of opportunities for future research in sustainability exist, including: 1) an evaluation system for sustainable FSCs that considers FLW reduction, 2) sustainable consumption initiatives and the impact on FLW reduction, 3) trade-offs to exercise a sustainable FSC between stakeholders, 4) quantification of FLW in circular supply chain models, 5) collaboration issues in the circular supply chain context, 6) government intervention for FLW management and construction of a sustainable FSC, 7) the roles of corporations, NGOs, and non-profit organizations for sustainable development with respect to FLW reduction, 8) the relationship between food security/safety and FLW management, and 9) the carbon footprint of FLW and the relationship between FLW reduction and carbon neutrality.

*7.2. FSC management*

FSC management has been widely analyzed in existing publications. However, discussions on FLW reduction that relate to the entire FSC, including FSC cooperation and risk management, remain relatively scarce.

*7.2.1. Cooperation*

Nearly one-fifth of the interview questions relate to FSC cooperation, and over half of the interviewees mentioned cooperation is one of the most important issues affecting FLW reduction. Our interview data show that FSC cooperation helps to reduce FLW for both large companies and SMEs. A purchasing manager at a leading food processing company explained that "Our company strengthened the cooperation with upstream suppliers to reduce the food loss, which has dropped around 1-2% compared with 4 years ago", and a head of a small cooperative indicated that "We tried hard to strengthen cooperation with supermarkets, wholesalers, and processors, which reduced the food loss rate by around 5% in the sales stage". However, we identified only seven papers out of the 346 papers that studied FLW through the lens of FSC cooperation, a reflection of the fledgling state of this research area. Our review of the literature reveals two potential directions for future research in relation to cooperation: FLW transmission mechanisms and coordination mechanisms.

We define the FLW transmission mechanism as how the FLW costs or burdens are transmitted from the upstream to the downstream, or vice versa. In practice, improper treatment of the food in the upstream of the FSC, including packaging, handling, transporting, and warehousing, may cause FLW downstream. Studies could investigate how transmission mechanisms might work to minimize FLW.

From a holistic and network perspective, cooperation has been suggested as an appropriate strategy to reduce FLW (Halloran et al., 2014). Future studies could consider modeling or describing different variables in coordination mechanisms relating to FLW reduction, such as different FSC stakeholders and their roles and power in cooperation. For instance, a chief executive officer (CEO) at a small fruit and vegetable wholesale company explained "Our company is a small-size company, and we lack marketing power to cooperate with upstream suppliers or downstream retailers". Other future directions include changes and uncertainties in the network during cooperation and different contract types and their impacts on FLW reduction. In particular, contract management is considered to be an effective way to reduce FLW. A manager at a leading beverage company stated that "We gradually strengthened our cooperation with the downstream of our supply chain by contract management and retailer management and it contributes to around 1-2% in FLW reduction". Possible research topics could include: 1) how the transmission mechanism works to minimize FLW in FSCs, 2) FLW reduction performance evaluation during cooperation between the FSC stakeholders considering different marketing power of the stakeholders, 3) innovative cooperation between stakeholders, 4) cooperation mechanism design in the context of multi-stakeholders, 5) the impact of rejection rate on FLW due to unsatisfied quality in the cooperation, 6) the concept of FSC integration to increase FLW reduction, and 7) an appropriate contract management to reduce FLW.

### *7.2.2. Risk management*

Our interview data show that many companies are working on FSC design and risk management to reduce FLW, especially for large food processors, traders and chain retailers. A operations manager at a vegetable trade company stated that "We are planning to invest in risk management to reduce FLW and hope to obtain the OM researchers' suggestions". While FSC risk management has been well investigated in recent publications (Behzadi et al., 2018), we could only find one paper (Ali et al., 2019) that also considered FLW reduction.

Scholars often classify supply chain risk into two categories: disruption risks and operational risks (Tang, 2006). The difference between these two types of risks is whether they are caused by human-made and natural disasters or operational uncertainties. Identification of potential risks in the treatment of FLW is important. For instance, given specific circumstances, accepting some FLW might be economically efficient; however, if corporations are forced to reduce their FLW with costly interventions, this might lead to financial problems within the entire FSC. Another example relates to the redistribution of unsaleable products. Holweg et al. (2016) suggest that even though some unsaleable products are still edible and redistributable, there might be potential health risks involved owing to a lack of refrigerated facilities during the redistribution. Uncertainty in customer demand is another potential risk to consider in FLW management. For example, customers might not accept the by-products converted from retail FLW. Potential areas of investigation relating to risk management in FLW include the potential impact of FLW reduction strategies on FSC disruption and uncertainties in the FLW reduction process, which impact other food value chain stages.

### *7.3. Operations and technology application*

Although issues relating to FLW are more frequently examined within the context of a specific stage in the FSC, a number of research gaps still remain in operations-based activities and technology application.

#### *7.3.1. Demand forecasting and farmer behavior*

A manager at a beverage company concluded that “In our company, the root-cause of food loss is mostly owing to the inaccuracy of forecasts, which leads to over-production”, and another purchasing manager at a food production company further explained that the reasons for FLW are various, including “suppliers’ behavior, learning experience, and willingness to obey the contract”. Further exploring the literature, we identify that demand forecasting and farmer behavior are two possible research topics. Demand forecasting is not only a technical problem; thus, OM methods could be productively employed to resolve the challenges at hand. While there are studies that focus on uncertainty problems in FSCs, there is still a need for further work in modeling yield, price, and demand to improve demand forecasting accuracy and accordingly reduce FLW.

Farmer behavior is another promising area of research. In practice, farmers are not always price sensitive and their transactions may be affected by trade-offs between extra transaction costs and the benefits from a higher selling price. In addition, farmer behavior may also be influenced by transaction habits rather than current conditions when making decisions. Our search did not yield any papers that deal with FLW issues in relation to demand forecasting and farmer behavior.

*7.3.2. Processing*

Quantitative analysis based on qualitative research findings in the processing stage is thought to be underdeveloped (Raak et al., 2017). We could only find three papers investigating FLW issues in the processing stage (Raak et al., 2017; Redlingshöfer et al., 2017; Simms et al., 2020), and all of them use qualitative methods.

In practice, we observe that processing planning, decisions on new technology adoption, and managing material surplus can impact FLW reduction performance in the processing stage. A head at a farmers' cooperative stated that "We introduced new planting technology and invested in new processing facilities, which greatly decreased the suboptimal tomatoes. These methods reduce the rate of suboptimal tomatoes from 15-25% to around 5%. It effectively reduced the food loss".

These effects remain to be discussed, which provides significant opportunities for FLW management contributions. Moreover, modeling the uncertainties during the processing stage is also a promising avenue, for example, uncertain rejection rates. The design of an appropriate processing plan and investment decisions around the application of new technologies which consider the trade-offs between the investment cost and FLW reduction performance are also research topics that beckon attention.

*7.3.3. Distribution optimization*

Distribution channels are quite different across different FSCs and may include diverse stakeholders and processes. These differences could impact FLW reduction operations (Song et al., 2021). Some studies focus on e-commerce or internet retail, while other studies deal with physical stores such as supermarkets; there is a lack of comparative studies on how different modes of FSCs affect FLW, and we only found two such papers. Accorsi et al. (2014) consider a different network layout that can cause different FLW problems. Song et al. (2021) discuss the omni-channel strategies and their impacts on FLW.

Possibly driven by technology and information availability, omnichannel distribution has become a burgeoning practice, which changes the interaction between retailers, manufacturers, and customers. The involvement of new distribution channels may positively or negatively influence FSC management and FLW reduction. Consequently, various FSC stakeholders voiced out the challenges they faced in distribution optimization, spanning across channel optimization, network optimization, and overall system optimization. Additional research can provide insights into omnichannel distribution, a relatively new mode of distribution. Interesting topics in the context of FLW reduction include studying customer choice of distribution channels and the economic value of omnichannel options, challenges and opportunities in omnichannel operations, and the impact of omnichannel distribution on FLW reduction performance.

*7.3.4. Technology application*

Technology application has been mentioned by several interviewees. It is one approach to effectively reduce FLW, with benefits that include keeping food fresh, extending the life-cycle, and changing the appearance and size of the food products. For instance, a vice president at a vegetable company indicated that "advanced package and pre-cooling facilities possibly reduce 10-20% of loss". Exploring the extant literature, agricultural-specific technologies and high-technology foods are two dimensions in Agriculture 4.0[1] (Olsen and Tomlin, 2020) that could possible help to reduce FLW. As another emerging technology, blockchain is considered an important tool to enhance supply chain visibility (Rogerson and Parry, 2020; Mangla et al., 2021). The problem of tracking

[1] "Agriculture 4.0", which is a reference to "Industry 4.0", is defined as an agricultural revolution brought about by advanced science, technologies, and devices (De Clercq et al., 2018).

and tracing in FSCs has been discussed widely (Derqui and Fernandez, 2017); however, blockchain applications in FLW reduction are still scarce.

The application of new techniques can have a considerable impact on FSC management and FLW reduction in that they: 1) may disrupt the traditional links in FSCs; 2) may improve production efficiencies despite increasing costs in the short-term; 3) may reduce uncertainty in the FSC, while creating other types of risks, such as investment risk in new techniques; and 4) may involve new recycling technology or FLW treatment methods, while increasing disposal costs.

However, the interview result also indicates that the universal applicability of techonology to reduce FLW are questioned and challenged in practice. Normally the large companies could effectively control the FLW by applying techonology. Whereas, counter-intuitively, when the SMEs replicate or learn from the large companies in techonology application, the performance in reducting FLW is sometimes unsatisfying.

Over fifty percent of the interviewees are expecting help from OM researcher in relation to technology applications. The concerns include "being a small size wholesaler, we have no financial budget to pay for the technology" (a CEO at a small wholesale company), and the different performance of technology between large companies and SMEs. For instance, a manager at a large beverage company indicated that "RFID [radio frequency identification] technology effectively improved the effiency of our operations", whereas, a vice president at a small food manufacture company said "We tried many methods such as changing packaging and using iced-water bottles for pre-cooling. However, these methods are not effective enough". An associate director in the government summarized that "In fact, large companies usually have effective methods including technology application, while it is the contrary situation for SMEs".

Our review did not locate any papers that discussed the trade-offs in new technologies within the context of Agriculture 4.0 and/or blockchain contexts. As suggested by OM researchers (e.g., Zhang and Jiang, 2017), future research into aspects of new technology application in FLW management is needed. Interesting topics include, 1) the trade-offs between the benefit and cost of new technologies with respect to FLW reduction, 2) the influence of aesthetic grading on FLW, 3) the efficiency of government interventions on the application of new technologies that impact the FLW performance, 4) the technical limitations that reduce transformation for by-products, 5) the trade-offs between adopting new technologies and minimization of rejection rates, and 6) the optimal investment strategy in technology considering the possibility of failure in technology application, particularly, focusing on SMEs' strategic technology investment decision.

We presented our future research directions above to the interviewees for checking against their practical needs, and the feedback was positive. All the interviewees thought this paper addressed important concerns. It is therefore meaningful for OM researchers to devote attention to FLW research in these directions and we hope that this paper stimulates research endeavors for reducing FLW in supply chain operations.

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