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Digitally Enabled Food Sharing Platforms Towards Effective Waste Management in a Circular Economy: A System Dynamics Simulation Model

By

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Declaration

I hereby declare that the content and organization of this dissertation constitute my own original work and do not compromise in any way the rights of third parties, including those relating to the security of personal data.

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8- **Ranjbari, M.**, Shams Esfandabadi, Z., Scagnelli, S. D., Siebers, P.-O., Quatraro, F., 2021. Recovery agenda for sustainable development post COVID-19 at the country level: developing a fuzzy action priority surface. **Environment, Development and Sustainability**. 2021, 23, 16646–16673. https://doi.org/10.1007/s10668-021-01372-6

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10- **Ranjbari, M.**, Shams Esfandabadi, Z., Ferraris, A., Quatraro, F., Rehan, M., Nizami, A.-S., … Tabatabaei, M., 2022. Biofuel supply chain management in the circular economy transition: An inclusive knowledge map of the field. **Chemosphere**. 296, 133968.

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Abstract

Food waste (FW) is large in supply chains due to the increasing population and the need to mass production and produce food on an industrial scale. Approximately, one-third of all food produced in the world is wasted, which poses a significant challenge to the global economy and the environment. Hence, mobilizing food supply chain stakeholders and policymakers to fight against food waste and loss is of great importance in the food sector. In this regard, while FW research has been mainly focused on FW recovery and energy production, less attention has been paid to FW prevention and consumption patterns. Consequently, incorporating FW prevention initiatives at the consumption level into national policy agendas seems crucial in effective FW management in transitioning towards a circular economy (CE).

As a solution to tackle the FW challenge, alternative distribution channels in food supply chains using digital platforms have recently gained attention. In this vein, digitally enabled food sharing platforms (FSPs) with a particular focus on FW prevention are emerging as FW warriors and anti-waste social movements. On the one hand, the number of users of such platforms is rapidly increasing. This might come from different motivations, such as FW prevention, economic saving, accessibility, and social exposure. However, it is still not clear how the diffusion of such food sharing apps will take place in the future. On the other hand, in contrast with the increasing number of users, the effective usage of such platforms, referring to the amount of FW prevented per user is relatively low. Hence, the contribution of FSPs to the CE by preventing FW is still lacking. On this basis, the paradox of a highly increasing number of users with relatively low effective usage of such FSPs encourages further investigations.

As the first attempt in literature, this thesis aims at simulating the diffusion of digitally enabled FSPs over time and predicting their impact on FW prevention and

the CE transition. To this end, a System Dynamics simulation model is developed to unfold (i) how people adopt such platforms over time, (ii) how such platforms contribute to the CE through FW prevention, and (iii) how different levels of knowledge-enhancing activities and marketing plans can affect the adoption and performance of such platforms over time. To develop the model, the Too Good To Go (TGTG) platform in Italy is considered as the case, which is one of the most well-known FSPs already active in 17 countries in the world.

The simulation is carried out for the period 2015-2060 based on the current achievements of the TGTG platform in the Italian market in terms of the number of users and the number of food bags saved. In this regard, different scenarios using three criteria (i.e., start time, duration, and effectiveness) are run to map the effect of marketing efforts and knowledge-enhancing activities (both for adult and under-aged populations) on TGTG's diffusion and performance over time in terms of (i) the number of users, (ii) the amount of FW prevented, (iii) the average number of saved food bags per user per year, and (iv) the contribution of TGTG to the FW prevention of the country towards a CE.

The results showed that although TGTG is a successful FSP in terms of the number of users (adoption), it can still significantly improve in terms of its contribution to FW prevention (performance). In this vein, the simulation outputs showed that (i) the current marketing campaign and social media efforts for TGTG are strong, adequate, and effective. Hence, keeping this marketing force active for almost 10 years can result in a successful and sustained market for this rapidly growing app in terms of the number of users, (ii) unlike the marketing campaign, knowledge-enhancing programs and activities should be strengthened to enhance the performance of TGTG in contributing to the CE transition through increasing the average number of saved food bags per user. In particular, testing different scenarios outlined that (i) longer-period and more effective knowledge-enhancing programs can still increase the number of app users by increasing their knowledge about the food sharing app and its positive impact on the environment and transitioning towards a CE, and (ii) even if the number of the users of TGTG app reaches the maximum potential number, knowledge-enhancing programs can still work towards increasing the attractiveness of more frequent usage of the app and save a higher amount of food products from being wasted. Hence, a winning policy was recommended with especial focus on knowledge-enhancing activities which can lead to a reduction of approximately 3% in the total FW generated at the country level in 2060.

The provided insights regarding the dynamics of performance and diffusion of FSPs can notably guide food supply chain stakeholders, policymakers, and practitioners to foster transitioning towards a circular food system. Although the developed diffusion model was built for the TGTG platform in Italy, it is a general model that can be used for any number of other FSPs in any other region.

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Section I

Introduction

Chapter 1: Introduction

1.1. Introduction

Due to the growing population of the world and rising living standards, the consumption of goods, and consequently, waste generation levels have been considerably increasing over recent years (Malinauskaite et al., 2017). For instance, an estimated 2.01×10^9 t of municipal solid waste was generated in the world in 2016, and it is expected to grow to 3.40×10^9 t by 2050 (Kaza et al., 2018), which sounds alarming as a universal issue. Designing and managing an efficient waste management system, as a foundation for the circular economy (CE) establishment (Di Foggia and Beccarello, 2021), is crucial to achieving better resource management and more waste prevention (Zeller et al., 2019).

Traditional business models mainly operate based on the "take-make-dispose" model, in which virgin raw material is extracted, products are produced and sold to end customers, and at the end-of-life, these products become wastes and are discarded by the customers (Khandelwal and Barua, 2020; Patwa et al., 2021). This linear-based approach of production and consumption depletes non-renewable resources and leads to severe ecological, economic, and social impacts on the global community (Ritzén and Sandström, 2017). Hence, due to global concerns about the sustainable environment and resource efficiency, the transition from a linear economy to a CE has gained momentum in recent years as a solution to tackle the associated challenges through increasing resource efficiency, minimizing waste, and reducing emissions during product lifecycles (Farooque et al., 2019; Korhonen et al., 2018).

The CE with a regenerative nature focusing on closing the supply chain loops significantly relies on effective waste management practices from waste prevention at the top of the waste hierarchy to disposal at the bottom (Ranjbari et al., 2021a). In this regard, implementing the CE within the various ranges of industries and sectors, such as the automobile industry (Patel and Singh, 2022), the construction industry (Charef et al., 2021), the textile and clothing industry (Saha et al., 2021), food supply chains (Kazancoglu et al., 2021), and municipal solid waste treatment systems (Fan et al., 2020) has been under intense investigations. Nevertheless, putting the CE in place faces significant challenges and it is still unexplored due to the primary focus on the linear economy model (Ardra and Barua, 2022).

The food industry as a global complex network of various businesses to provide people with food is one of the largest industries in the world. Food waste (FW) is large in supply chains due to the increasing population and the need to mass production and produce food on an industrial scale. On this basis, FW has brought a wide range of adverse effects on society, the economy, and the environment (Wu et al., 2021). As reported by the Food and Agriculture Organization, one-third of all food produced worldwide is wasted, which accounts for approximately 1.3 billion tons (de Castro et al., 2020). For instance, the current agricultural system in Europe has generated approximately 700 million tonnes of agro-food waste per year (Fortunati et al., 2020). Therefore, there is an utmost need to mobilize all stakeholders involved in food supply chains to reduce food waste and loss in a more sustainable setting.

The agri-food sector has notable potential in transitioning toward a CE as well as a low-carbon and climate-friendly economy since FW is considered a significant contributor to global waste generation (Mehmood et al., 2021). In this vein, due to the complexity of food systems and potential conflicts among involved stakeholders within the food supply chain, creating closed loops and circularity within this industry face multiple challenges. Although the contribution of the food industry to the CE transition has been investigated from different perspectives from farm production to household consumption, the empirical research in this area is still in its infancy stage. Hence, encouraging sustainable consumption patterns and CE-oriented consumer behavior to enable the CE in practice is crucial.

While food loss mainly takes place at the production, postharvest, and processing phases of the food supply chain, FW mostly occurs at the end side of the chain, highlighting the need to consider habits, behaviors, and consumption patterns of consumers and retailers (Morone et al., 2018). In this vein, while in developing countries FW is mainly generated at the early stages of the food supply chain (i.e., food loss) due to technical and financial constraints, in developed countries FW largely arises at the later stages of the chain due to consumer behavior (Falcone and Imbert, 2017). Hence, incorporating FW prevention and reduction plans and incentives at the consumption level into national policy agendas seems crucial in effective waste management in transitioning towards a CE.

1.2. Research gap and objectives

Despite growing attention to the techno-economic dimensions of the CE transition among industries, policymakers, and academia, the role of the consumption side and consumer behavior in the CE remains largely under-researched (Georgantzis Garcia et al., 2021). Consumer behavior is key to enabling the CE mechanism and creating slower and closed loops within the supply chain of consumer goods and products. It is pivotal to build a policy toolkit at different levels of influence to encourage consumers to adopt new consumption patterns in line with CE principles.

The contribution of consumers to the development of the CE has been studied from various vantage points, such as green consumer behavior and the purchasing of circular packaging (Testa et al., 2020), consumer awareness of product circularity (Cordova-Pizarro et al., 2020), the effect of consumer behavior on the release of waste into the CE (Wilkinson and Williams, 2020), and consumer behavior barriers to the CE (de Jesus and Mendonça, 2018). Gullstrand Edbring et al. (2016) discussed consumer attitudes toward alternative consumption models based on circular flows of products and materials, including models for extending the product use stage (e.g., reselling of second-hand goods), access-based consumption patterns (e.g., renting and leasing), and collaborative consumption services (e.g., sharing platforms).

Online platforms, operating as digital marketplaces, streamline interactions among diverse participants on the platform by overseeing their communication, providing market insights, maintaining price transparency, assisting customers in their decision-making, and disseminating relevant information (Konietzko et al., 2019). Online platforms have the potential to support the implementation of a CE by enabling organizations and individuals to share access to underutilized physical assets, thus minimizing idle capacity and promoting the more efficient, sustainable management of resources within a CE (Konietzko et al., 2019). However, our comprehension of the organizational frameworks and the internal mechanisms of such platforms and how they work and create value within the food supply chain for involved stakeholders remains limited.

The advent of online networks and digital platforms has notably changed distribution and redistribution channels, leading to advancing sharing economy platforms to connect the demand and supply sides of any economic system (Ranjbari et al., 2018). In this regard, the food sector has also benefited from this digital revolution by developing food surplus redistribution channels and online platforms in recent years. In this regard, digitally enabled FSPs have emerged to prevent FW and save the environment in a CE paradigm.

Sharing durable products, such as bikes, cars, rooms and houses, services, instruments, etc., has gained momentum either in peer-to-peer or business-to-consumer business models. With this premise in mind, there has been a growing focus on the exploration of digital platforms for alternative distribution channels in food supply chains as a potential solution to tackle the FW challenge worldwide. However, using redistribution channels in the food sector is more challenging than other products since food is a particular type of product due to several facts, such as (i) food is a life necessity, (ii) food is a human right, (iii) food is highly sensitive in terms of health, safety, durability, and quality, and (iv) food has a specific social and cultural value (Zurek, 2016). Therefore, incorporating sharing economy in the food sector through digitally enabled platforms faces several barriers, including (i) trust among stakeholders, (ii) behavior and consumption patterns of different players within the food supply chain, and (iii) satisfying multiple needs for heterogeneous actors (de Almeida Oroski and da Silva, 2022).

In this vein, digitally enabled food sharing platforms (FSPs) have emerged to prevent FW and save the environment in a CE paradigm. FSPs enable local communities to address both FW concerns and food accessibility, as an effective action towards achieving sustainable development goals 2 (zero hunger) and 12 (responsible consumption and production) introduced by the United Nations (Lucas et al., 2021). Since this phenomenon is still new, there is no common understanding of the business model of such platforms and how they work and create value within the food supply chain for involved stakeholders. Michelini et al. (2018) categorized food sharing business models into three groups, including sharing for money, sharing for charity, and sharing for the community business models. Generally, food sharing initiatives have emerged to help societies reduce FW, mainly through FW prevention. However, any food sharing business model creates different values for different players within the food supply chain, including consumers, platform providers, and distributors.

In this regard, FSPs face several challenges, such as the impact assessment of food sharing on sustainability and CE (Mackenzie and Davies, 2019; Michelini et al., 2020), the rebound effects of such platforms for production and consumption (Meshulam et al., 2022; Yu et al., 2022), and the adoption of FSPs in urban communities (D'Ambrosi, 2018). However, given the novelty of the urban FSPs, the contribution of such initiatives to the CE transition in the food supply chain is still blurred (Sarti et al., 2017) and lacks sufficient empirical research.

On the one hand, the number of users of FSPs, such as Too Good To Go (TGTG) is notably increasing. For instance, TGTG's user count in Italy has experienced a rapid surge, surpassing 6.9 million users by the end of 2022 within less than four years (TGTG, 2022a). The main reasons behind such a rapidly increasing adoption rate might be (i) the willingness of people to prevent FW and help the environment through using such platforms, whose providers claim they are anti-waste warriors, and (ii) the economic attractiveness for some parts of the community, especially the vulnerable population who care about discounted prices offered by the points of sale through the TGTG app. However, the level of diffusion of using such platforms among communities in the future is not clear.

On the other hand, in contrast with the increasing number of users, the average number of saved food bags per user per year is quite low. For instance, in Italy, from March 2019 to the end of 2022, only 10 million foods (i.e., magic boxes) have been saved by 6.9 million TGTG users (TGTG, 2022a), which accounts for approximately less than 0.4 of a food bag per user per year. Hence, the paradox of a highly increasing number of users with a low effective usage of TGTG in terms of the number of food bags saved per user per year calls for further investigations. In other words, the contribution of FSPs to FW prevention and creating a circular food system is not clear and faces some challenges. While such platforms are frequently considered as a promising strategy to reduce FW (Makov et al., 2023), others argue that they can lead to a rebound effect and provide some extra lines of production and consumption (Meshulam et al., 2022; Yu et al., 2022). Hence, the potential of FSPs in preventing FW and supporting the circular food system over time is still blurred.

The contrast between the high number of FSP users and the low number of saved food bags highlights the familiarity of the people with these platforms to adopt it and their lack of adequate knowledge about the role these platforms can play in the sustainability transition. These two factors have also been acknowledged in the literature regarding the adoption of new technologies, platforms, and apps. For instance, according to Struben and Sterman (2008), subsidies and marketing programs in the long term play an important role in self-sustaining diffusion of alternative fuel vehicles and word of mouth can highly stimulate the diffusion of new technology. Moreover, Shams Esfandabadi (2022) highlighted the key role of knowledge-enhancing activities in the usage of carsharing, as a potentially sustainable mode of transport, and sustaining its market share.

TGTG has based its activities on four main pillars, including people, companies, schools, and politics (Fragapane and Mortara, 2022). On this basis, in addition to marketing, that is an inevitable part of any growing business, TGTG has targeted increasing knowledge of people regarding FW implications for societies and the environment to battle against FW. In this regard, (i) inspiring consumers to help with FW prevention by providing information and raising their awareness of the FW phenomenon, (ii) involving various food-related businesses, such as bakeries, restaurants, supermarkets, and hotels in FW reduction practices within different stages from food production to retail and consumption, (iii) organizing different classes and seminars in schools targeting FW information and awareness are among knowledge-enhancing activities of TGTG.

Therefore, this thesis aims at developing a computational model to simulate the diffusion of digitally enabled FSPs over time and predict their impact on FW prevention and the CE transition. To this end, a System Dynamics model is developed and the simulation results for the TGTG FSP in Italy as a reference case are presented. System Dynamics has been selected for this research as it is a proper tool to model complexities within a system and show the behavior of a system over a long period. To the best of the author's knowledge, this is the first diffusion model developed for FSPs, which significantly contributes to the research and developments in this emerging area of research in the food sector towards a CE. Using the developed simulation model, this article tries to answer the following questions:

- **RQ1.** What is the future outlook for the diffusion of digitally enabled FSPs in light of marketing and knowledge-enhancing activities?
- **RQ2.** To what extent can digitally enabled FSPs, supported by marketing and knowledge-enhancing activities, contribute to the prevention of FW within a CE over time?

The motivation behind this research is to address the need for understanding the diffusion and impact of digitally enabled FSPs on FW prevention and the transitioning towards a CE. The research seeks to fill a significant gap in the existing literature by developing a simulation model to provide valuable insights and contribute to the emerging field of research within the food sector towards achieving a CE. Hence, the provided insights contribute to the existing literature in several ways. Firstly, it aims to simulate the diffusion of digitally enabled FSPs over time, providing insights into their potential growth and adoption patterns. By developing a System Dynamics simulation model specifically tailored to the TGTG platform in Italy, this study serves as a pioneering effort in the field of FSPs, as no prior diffusion model for FSPs has been developed to the knowledge of the authors. Secondly, this research addresses two important questions that are crucial for the advancement of the food sector towards a CE. The first question (RQ1) focuses on predicting the future evolution of digitally enabled FSPs, shedding light on their potential reach and impact in the coming years. By exploring this aspect, the study provides valuable insights into the growth trajectory of FSPs, enabling policymakers and industry stakeholders to make well-informed decisions. The second question (RQ2) delves into the role of digitally enabled FSPs in addressing FW prevention within a CE framework. By investigating the extent to which these platforms can contribute to FW prevention, the research offers practical implications for reducing FW and advancing the principles of the CE.

1.3. Thesis organization

The thesis includes 5 sections containing 10 chapters. Section I including Chapter 1 presents the introduction of the thesis, highlighting the research gap and the main objective of the thesis. Section II provides an inclusive literature review of the topic with an up-down approach, including waste management research in the CE (Chapter 2), the science map of the FW research (Chapter 3), and FSPs (Chapter 4). Section III describes the case study of the thesis and the adopted methodology, including the TGTG platform in Italy (Chapter 5) and System Dynamics modeling (Chapter 6). Model development and scenario analysis are explained in detail in Section IV by presenting problem articulation and dynamic hypotheses formulation (Chapter 7), simulation model formulation and testing (Chapter 8), and scenario analysis and policy recommendation (Chapter 9). Finally, Section V concludes the thesis by delivering remarks, highlighting limitations, and proposing future research directions for further development (Chapter 10). The main structure of the current thesis is illustrated in Figure 1.

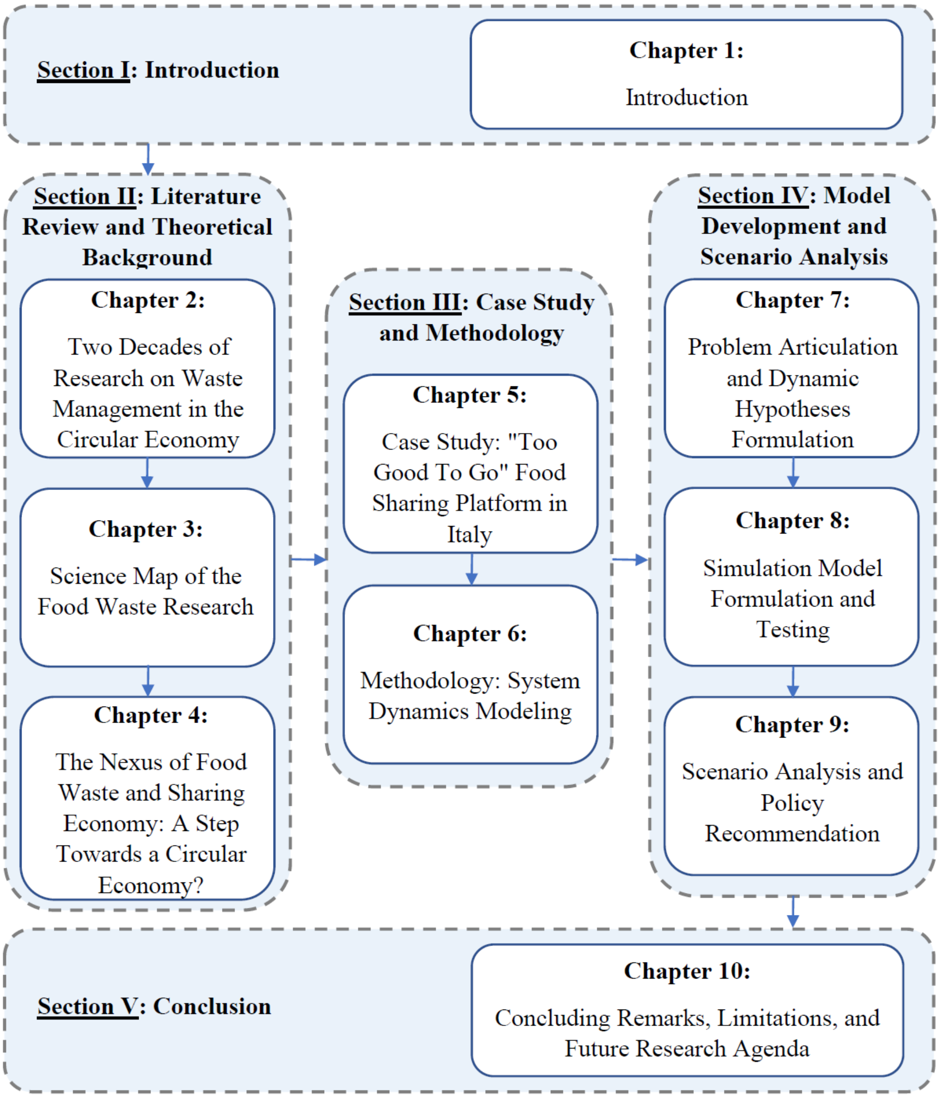


Figure 1. Thesis structure.

Section II

Literature Review and Theoretical Background

Section overview

This section includes three different systematic reviews with an up-down approach presented in three chapters.

- In the first chapter (Chapter 2), a comprehensive body of knowledge on waste management in the CE and its salient research themes and trends is provided. To this end, a mixed-method approach, including bibliometric analysis, text mining, and content analysis is applied.

- In the second chapter (Chapter 3), an inclusive knowledge map of FW research in the available academic literature is presented. In this regard, a systematic bibliometric analysis is performed employing keywords, and bibliographic coupling analyses on a total of 4459 peer-reviewed articles in the Web of Science database.

- In the last chapter (Chapter 4), the food sharing concept, as an application of the sharing economy in the food sector, is scrutinized and conceptualized through a systematic literature review. Hence, different food sharing business models, motivations for using FSPs, and food sharing implications for waste management towards a CE transition are presented and discussed.

Chapter 2: Two Decades of Research on Waste Management in the Circular Economy

2.1. Introduction

The CE intends to slow, narrow, and close supply chain loops by returning materials and waste into resources towards a sustainable economy and environment (Ranjbari et al., 2021a). In recent years, extensive research on waste management practices corresponding to the CE goals has been increasingly conducted. Those include but are not limited to developing CE indicators for waste management (Luttenberger, 2020), waste management drivers towards a CE (Calderón Márquez and Rutkowski, 2020), identifying barriers and challenges in the transition to a CE (Zhang et al., 2019), waste hierarchy index for the CE (Pires and Martinho, 2019), and enablers of E-waste management in a CE (M. Sharma et al., 2020).

Bibliometric analysis has assisted researchers in dealing with numerous publications in the waste management research arena towards a CE. Accordingly, various research teams have quantitatively analyzed and mapped the development of different lines of waste management in the CE on a broader outlook, such as municipal solid waste management (Tsai et al., 2020), waste incineration (Xing et al., 2019), and construction and demolition waste (Wu et al., 2019). However, waste management activities compliant with the CE principles in practice are still blurred in the existing studies (Tsai et al., 2020) and remain a challenge for waste management policymakers and CE practitioners. Consequently, a holistic map of the waste management research themes and trends aligned with CE perspectives is lacking in the literature.

The present review aims to provide a body of knowledge for waste management in the CE and its salient research themes and trends, and main characteristics by scrutinizing the waste management literature in the context of the CE over the last two decades (2001–2020). The provided analysis can serve as a base for a real-time manner guideline for future research in this area. To achieve the aim of this study, a mixed-method approach, including bibliometric analysis, text mining, and content analysis, is applied to answer the following research questions:

- **RQ1.** How has the field of waste management research evolved within the CE domain?
- **RQ2.** What are the salient research themes and trends of waste management in the CE?

To the best of my knowledge, there is no comprehensive research in literature that synthesized bibliometric, text mining, and content analyses concurrently in the field of waste management within the CE context. Therefore, this study is expected to immensely contribute to (i) capturing the scientific background of waste management research in the CE context and identifying its main themes and trends over the last two decades, and (ii) drawing an inclusive research landscape for the waste management system and its prominent highlight patterns, as a tool to support waste management policymakers and practitioners towards a CE transition.

The remainder of this chapter is structured as follows. Section 2.2 provides an overview of waste management practices towards a CE. Section 2.3 presents the adopted research methodology framework to conduct the systematic review. The obtained results from the bibliometric analysis, text mining, and content analysis on the waste management literature within the CE domain are discussed in section 2.4. Finally, the remarks on the provided insights are delivered in section 2.5.

2.2. Waste management in a circular economy: an overview of opportunities and challenges

Waste management refers to all the activities and actions required to manage waste from its inception to its final disposal through the collection, transport, and treatment phases (Rajaeifar et al., 2017). The appropriate management, mitigation, and valorization of waste are essential for a sound CE to transform our society towards a sustainable and zero-waste environment (Aghbashlo et al., 2019a). A proper waste management system enables collecting discarded, worn out, and/or obsolete products to prevent them from being left out in nature and polluting the environment (Nelles et al., 2016). However, such a waste management system enables the suitable processing of waste to facilitate their reinjection in CE loops, thus avoiding the extraction of primary materials (Romero-Hernández and Romero, 2018). Many scholars have indeed highlighted the importance of waste management systems as a key pillar in a CE to realize or make feasible most of the 10R strategies namely, R0 Refuse/Rethink, R1 Reduce, R2 Resell/reuse, R3 Repair, R4 Refurbish, R5 Remanufacture, R6 Repurpose, R7 Recycle, R8 Recover, and R9 Re-mine (Reike et al., 2018). Waste and pollution prevention are the key reasons or objectives for developing a CE (Bilitewski, 2012).

While the current momentum around the CE concept could foster actions for better managing waste globally, Zhang et al. (2019) remind us that waste management systems need to be smarter for a zero-waste CE vision. Moreover, through a systematic review of zero-waste studies published between 1997 and 2014, Zaman (2015) found out that although policymakers had embraced the zero-waste concept, there was still a lack of advanced work or applied research in the domains of zero-waste design, assessment, and evaluation. On this basis, it is of the utmost importance not only to demonstrate that waste management practices can be cost-saving and revenue-generating opportunities (Romero-Hernández and Romero, 2018) but also can guide and monitor the activities of companies and businesses towards more circular and zero-waste practices through appropriate circularity indicators (Saidani et al., 2019). For instance, Di Maio and Rem (2015) proposed a "CE index" as the ratio of the material value produced by the recycler (market value) to the intrinsic material value entering the recycling facility. According to the authors, such an index takes into account the strategic, economic, and environmental aspects of recycling and offers a manageable amount of information to support decision-making tools. While other indicators or metrics have been developed recently for a CE in waste management, such as the "waste hierarchy index" (Pires and Martinho, 2019), there is no widely acknowledged, commonly agreed (Zaman, 2015), or standardized index for waste management systems across countries or industrial sectors.

2.3. Research methodology

This review used a mixed-method approach that involved both quantitative and qualitative analyses in scrutinizing the literature of waste management in the CE, as presented in sections 2.3.1 and 2.3.2. The overall research design is illustrated in Figure 2.

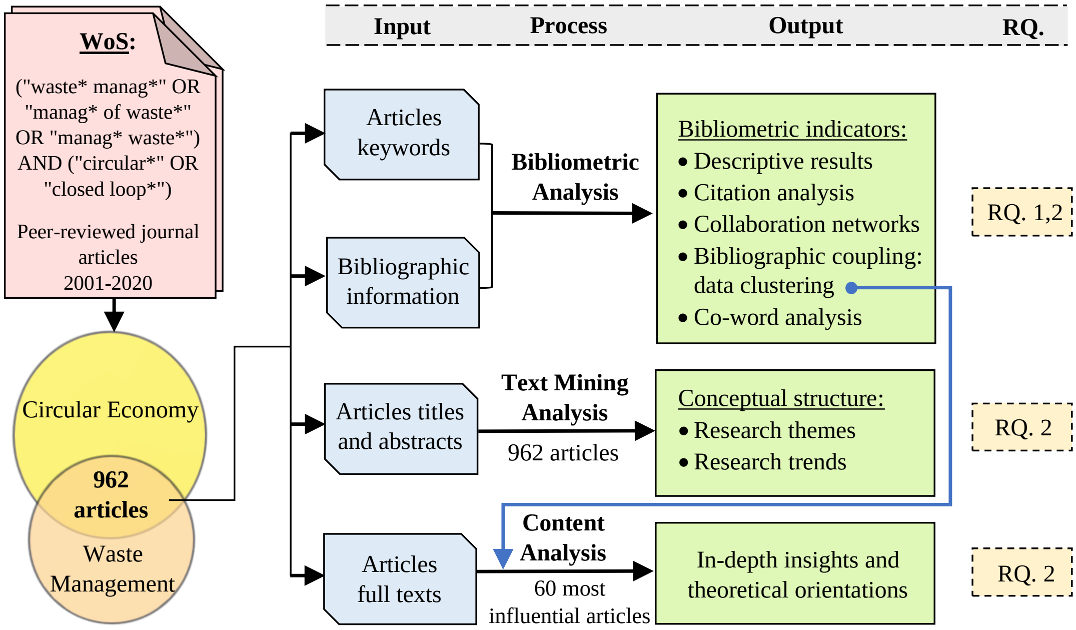


Figure 2. Review framework design.

2.3.1. Data sampling, collection, and cleaning

To ensure sufficient coverage of related publications within the field of study, the Web of Science Core Collection, as one of the most leading sources of scientific publications, was selected for collecting data in this review. The following search string was used to explore within the title, abstract and keywords fields: ("waste* manag*" OR "manag* of waste*" OR "manag* waste*") AND ("circular*" OR "closed loop*"). The initial search was conducted in January 2021 and was limited to peer-reviewed journal articles and reviews in the English language and the period of 2001–2020. After removing missing values, a total of 962 articles met the selection criteria and were used as the final sample for the analysis. As a fundamental preparation step for the keyword-based analyses, the final dataset was cleaned before conducting the bibliometric and text mining analyses (Ranjbari et al., 2020). In this vein, synonyms such as environmental effect and environmental impact, or E-waste and electronic waste, were merged. Besides, the unification of writing styles and merging singular and plural forms of the keywords were done, and keywords without any explicit meaning for this study's focus, such as "literature review" and "article", were removed from the dataset to increase the analyses' reliability.

2.3.2. Data analysis

Three analytical methods, including bibliometric, text mining, and content analyses, were employed in this review to examine the evolution and structure of the research field.

2.3.2.1. Bibliometric analysis

Bibliometric analysis, a quantitative technique and powerful statistical tool to deal with a large number of publications and scientific literature mapping, has been increasingly used in recent years in various fields of research, such as the CE (Goyal et al., 2020), sustainable development (H. S. Du et al., 2021), and open innovation (Gao et al., 2020). The bibliometric analysis supports researchers in quickly identifying future research directions within a field of study by providing an inclusive visualization of relationships among articles, journals, keywords, citations, and co-citations networks (Feng et al., 2017). VOSviewer version 1.6.16 was used to conduct the bibliometric analysis (van Eck and Waltman, 2010). Different bibliometric parameters, including publications evolution over time, citation analysis for core publications, collaboration analysis for countries and institutions, bibliographic coupling network analysis for data clustering, and finally, co-word analysis for identifying hotspots were presented in this part to statistically map the bibliometric information of scientific publications in waste management within the CE context over the last two decades.

2.3.2.2. Text mining analysis

Text mining technique, a tool for extracting information from an extensive collection of documents in text form and analyzing research themes and trends (Jung and Lee, 2020), has been widely employed by researchers in various fields of CE studies. Text mining analysis can particularly capture semantic structures and phrase patterns that best characterize a vast amount of text data. A text mining analysis based on a term co-occurrence algorithm was employed in this section on the concatenation of the titles and abstracts of the publications within the dataset using VOSviewer version 1.6.16. As a result, the conceptual structure and latent research themes and trends of the waste management literature in the CE domain were identified.

2.3.2.3. Content analysis

In line with the research conducted by Schöggl et al. (2020) and Jia and Jiang (2018), a content analysis, as a complementary qualitative layer, was also carried out in this review to improve the confidentiality of the results and to provide more in-depth insights for the quantitative findings of the investigation. In this sense, a qualitative content analysis using the data clustering technique was conducted for the top 15 most influential articles within each cluster obtained from the bibliographic coupling analysis to investigate the theoretical orientations in waste management towards the CE.

2.4. Results and Discussion

To address the research questions of this chapter, the results are presented in sections 2.4.1, 2.4.2, and 2.4.3, corresponding to the respective research questions.

2.4.1. Bibliometric mapping of extant studies

The bibliometric analysis indicators are presented in this section to directly address the first research question:

- **RQ1.** How has the field of waste management research evolved within the CE domain?

2.4.1.1. Descriptive analysis: publications evolution

Figure 3 illustrates the publication trend of waste management -related research in the CE from 2001 to 2020. The majority of articles (i.e., 910 out of 962) were published after 2014, accounting for over 94% of the data sample. It could be concluded that the primary research period in terms of the number of publications and academic involvement in waste management towards a CE would be from 2015 to 2020. Consistent with Reike et al. (2018), this significantly increasing number of scholarly publications in the last five years denotes that the CE establishment has received growing attention within different domains, such as waste management.

A total of 254 journals have published 962 articles on waste management considering CE from 2001 to 2020. The top 10 journals contain 513 out of 962 items, representing 53% of the publications in the field of waste management corresponding to the CE perspectives, and are shown in Figure 3. In this regard, Journal of Cleaner Production played the most dominant role in this field, with 141 out of 962 articles, constituting approximately 15% of the publications, and was followed by Sustainability, Waste Management, and Resources, Conservation & Recycling with 91, 75, and 73 articles, respectively.

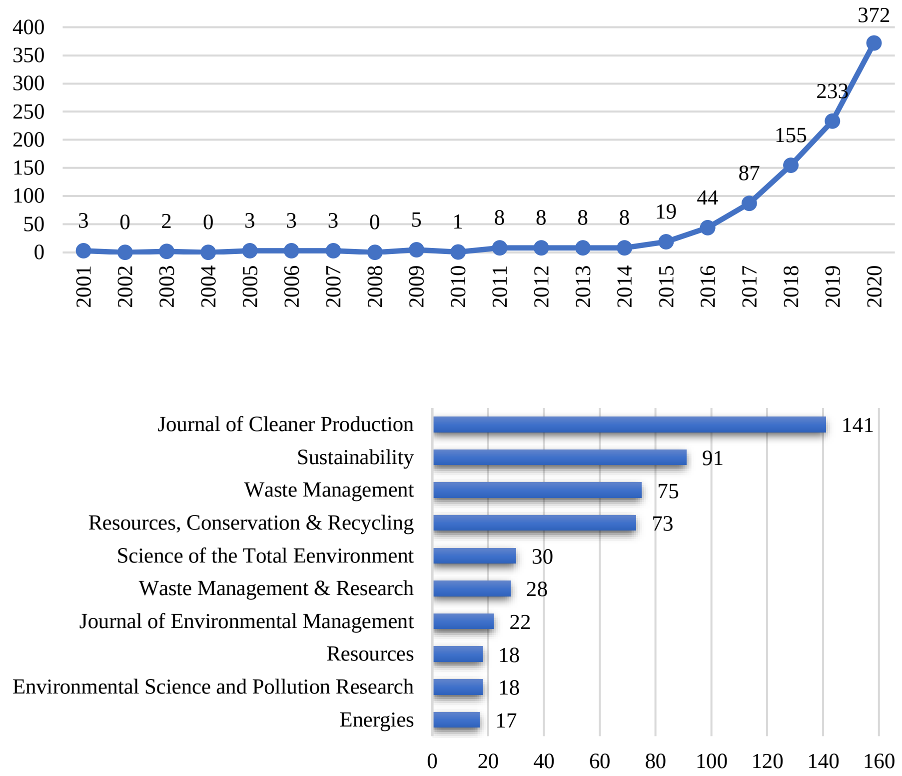


Figure 3. Publications evolution in terms of number and leading journals over time from 2001–2020.

2.4.1.2. Citation analysis: core articles

The number of citations received by an article can be considered a suitable measure for identifying the most influential publications in a research domain (Merigó et al., 2015). The top 10 highly cited articles within the studied dataset are shown in Table 1. Six out of 10 highly cited articles have been published in Journal of Cleaner Production, which denotes this journal's significant contribution to the transition from a linear economy to a CE. The most cited paper is a comprehensive review of the CE implementation conducted by Ghisellini et al. (2016), which has been cited 998 times until January 22, 2021, based on the Web of Science database. The next highly cited research works have been carried out by Lieder and Rashid

(2016), reviewing CE implementation in the manufacturing industry, and Su et al. (2013), assessing the CE development in China, respectively. As can be seen from Table 1, the most cited papers in this research area are review articles focusing on the CE perspectives and implementation. This may have occurred due to two reasons. First, the CE transition, on account of its potential advantages for economic and environmental regimes, has been the focal point of attention for researchers over the last few years. And second, implementing CE in practice is still challenging for policymakers and lacks a clear guideline for practitioners involved in operation levels.

Table 1. The top 10 highly cited articles in the waste management research towards the CE.

Rank	Article title	TC*	TC/Y**	Author(s)	Journal
1	A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems	998	166.33	(Ghisellini et al., 2016)	J Clean Prod
2	Towards circular economy implementation: a comprehensive review in the context of manufacturing industry	501	83.50	(Lieder and Rashid, 2016)	J Clean Prod
3	A review of the circular economy in China: moving from rhetoric to implementation	374	41.56	(Su et al., 2013)	J Clean Prod
4	Concurrent product and closed-loop supply chain design with an application to refrigerators	230	12.11	(Krikke et al., 2003)	Int J Prod Res
5	A review of reverse logistics and closed-loop supply chains: a Journal of Cleaner Production focus	204	40.80	(Govindan and Soleimani, 2017)	J Clean Prod
6	Sewage sludge disposal strategies for sustainable development	198	39.60	(Kacprzak et al., 2017)	Environ Res
7	Strategies on implementation of the waste-to-energy supply chain for the circular economy system: a review	187	26.71	(Pan et al., 2015)	J Clean Prod
8	The history and current applications of the circular economy concept	186	37.20	(Winans et al., 2017)	Renew Sust Energ Rev

9	Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe	178	35.60	(Malinauskaite et al., 2017)	Energy
10	How do scholars approach the circular economy? A systematic literature review	161	40.25	(Merli et al., 2018)	J Clean Prod

* Total citation; ** Total citation per year

2.4.1.3. Collaboration analysis: institutions and countries

Out of 88 countries and 1248 institutions contributing to the studied sample, the most contributing countries and institutions on the subject are illustrated in Figure 4. In this figure, the larger each circle is, the higher the number of documents the corresponding country and institution have. Moreover, the thicker the link between the circles, the more collaboration has occurred between them. Based on the results, Italy, England, Spain, China, and the USA are the pioneers in waste management research in the context of CE with 118, 117, 95, 93, and 83 articles, respectively. In terms of collaboration, China, with 126 international collaborations, is the leading country within the global network on the subject. England with 112, and Italy and the USA, both with 100 collaboration links, come next in this network. On the contrary, Poland with 25, and Brazil with 22 collaborations have the least developed network among the top 10 contributing countries.

Due to the large number of institutions involved in this study (n= 1248), only the institutions with at least three articles have been plotted in Figure 3 to better visualize the highly contributing institutions. Surprisingly, although The Netherlands and Greece are not among the top 10 contributing countries on the subject, the Delft University of Technology from The Netherlands and Aristotle University of Thessaloniki from Greece are equally the most active institutions with 14 contributions. The Polish Academy of Sciences from Poland with 13, the University of Cantabria from Italy, the Technical University of Denmark from Denmark, and the Chinese Academy of Sciences from China all together with 12 articles are the next most contributing institutions. Besides, the Delft University of Technology, Chinese Academy of Sciences, and Polytechnic of Milan with 36, 31, and 29 collaboration links are the most actively collaborating institutions among all institutions in this study.

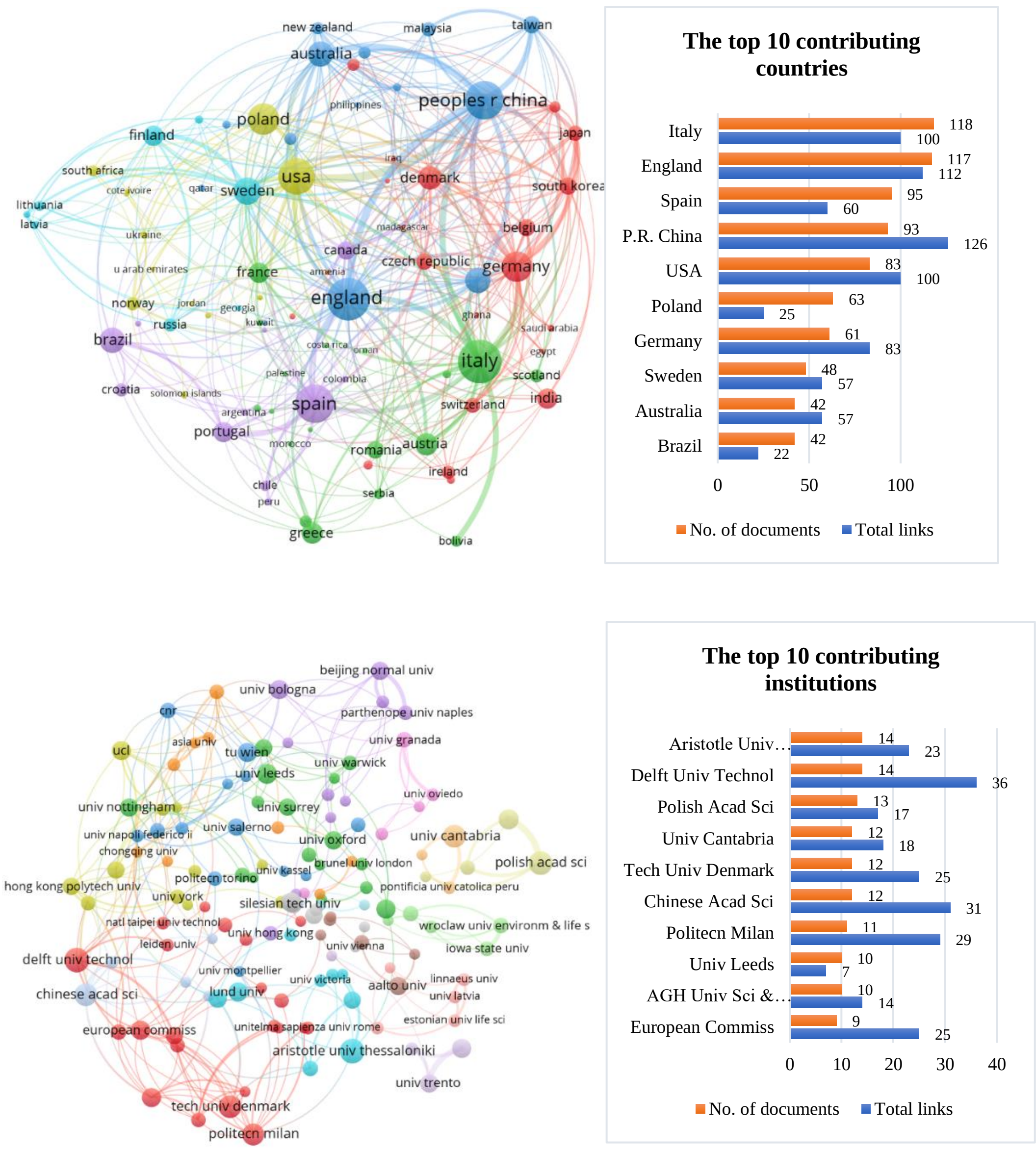


Figure 4. Collaboration network between countries and institutions in waste management research towards the CE.

2.4.1.4. Bibliographic coupling network analysis: data clustering

The data clustering technique to group the articles with analogous characteristics from a sample for identifying the research orientations (H. S. Du et al., 2021) is a typical application of bibliometric analyses. Bibliographic coupling analysis using VOSviewer was applied to perform data clustering in this part of the study. Bibliographic coupling links between publications indicate the number of cited references they have in common (van Eck and Waltman, 2020). A total number of 926 out of 962 articles in the sample was used to construct the bibliographic coupling network, as shown in Figure 5. According to the results, four clusters of articles were generated, which are shown in different colors in Figure 5.

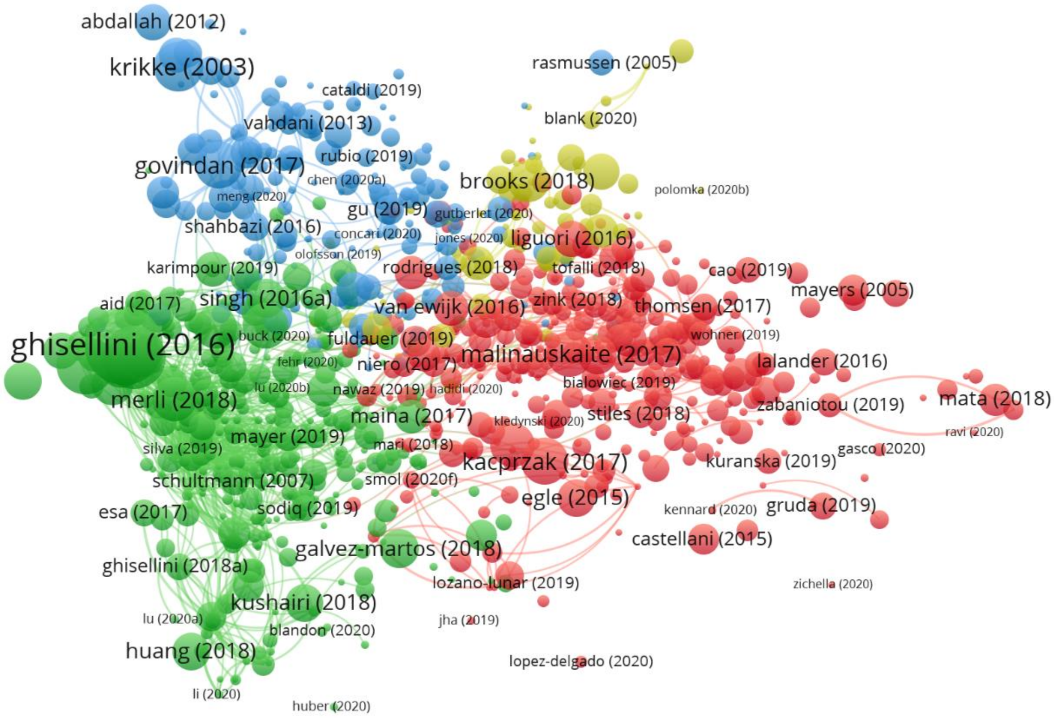


Figure 5. Bibliographic coupling network of waste management research towards the CE.

The four main clusters of articles are: (i) CE perspectives on waste hierarchy (cluster 1), (ii) CE conceptualization and implementation (cluster 2), (iii) waste management within closed-loop supply chains (cluster 3), and (iv) CE approach to plastic waste management (cluster 4). The top 15 most influential articles (i.e., highly cited articles) of each cluster are listed in Table 2. The obtained bibliographic coupling clusters and their influential articles will be addressed in detail in section 2.4.3 to conduct the qualitative content analysis and uncover the major themes and research orientations.

Table 2. The top 15 most influential articles within main clusters of waste management research towards the CE.

Cluster 1: CE perspectives on the waste hierarchy	**Cluster 2:** CE conceptualization and implementation	**Cluster 3:** waste management within closed-loop supply chains	**Cluster 4:** CE approach to Plastic waste management
Kacprzak et al. (2017)	Ghisellini et al. (2016)	Krikke et al. (2003)	Brooks et al. (2018)
Malinauskaite et al. (2017)	Lieder and Rashid (2016)	Govindan and Soleimani (2017)	Sakai et al. (2011)
Smol et al. (2015)	Su et al. (2013)	Abdallah et al. (2012)	Koop and van Leeuwen (2017)
Sandin and Peters (2018)	Pan et al. (2015)	Lee and Chan (2009)	Horodytska et al. (2018)
Egle et al. (2015)	Winans et al. (2017)	Ferronato and Torretta (2019)	Van Eygen et al. (2018)
Liguori and Faraco (2016)	Merli et al. (2018)	Islam and Huda (2018)	Jambeck et al. (2018)
Van Ewijk and Stegemann (2016)	Reike et al. (2018)	Nikolopoulou and Ierapetritou (2012)	Payne et al. (2019)
Haupt et al. (2017)	McDowall et al. (2017)	Lu et al. (2015)	Pomberger et al. (2017)
Iacovidou et al. (2017b)	Gálvez-Martos et al. (2018)	Ferronato et al. (2019)	Eriksen et al. (2019)
Iacovidou et al. (2017a)	Singh and Ordoñez (2016)	Krikke et al. (2013)	Prieto (2016)
Blengini et al. (2012)	de Jesus and Mendonça (2018)		Eriksen et al. (2018)

Agudelo-Vera et al. (2011)	Huang et al. (2018)	Vahdani et al. (2013)	Iacovidou et al. (2019)
Mata et al. (2018)	Bachmann (2007)	Gu et al. (2019)	Faraca and Astrup (2019)
Mayers et al. (2005)	Kushairi et al. (2018)	Özceylan et al. (2017)	Foschi and Bonoli (2019)
Nižetić et al. (2019)	Dong et al. (2013)	Pedram et al. (2017)	RameshKumar et al. (2020)
		Shahbazi et al. (2016)	

2.4.1.5. Co-word analysis: identifying hotspots

Authors' keywords in the articles can represent the main idea and border of their research. The co-word analysis based on the co-occurrence of words can support identifying research hotspots in a particular field of study (Gao et al., 2020). Before conducting the co-occurrence analysis, the keywords list was cleaned reasonably. In the end, 2641 out of 2889 keywords remained for the analysis. Excluding the keywords with a co-occurrence frequency below seven (for clearer visualization), the co-occurrence network of the authors' keywords containing 68 hot keywords is mapped in Figure 6. In this map, the bigger the circles are, the more occurrence the keywords have, and the thicker the links between every two keywords are, the more co-occurrence they have. Besides, the circles' color corresponds to the average publication year of the articles in which a keyword occurs. Moving from dark blue to yellow shows that the documents containing the relevant keywords are more recent on average.

The 10 most frequent keywords in the used dataset are CE, waste management, recycling, sustainability, lifecycle assessment, municipal solid waste, waste, FW, industrial ecology, and material flow analysis. These ten keywords also have the most connection links with the other keywords in the dataset. As shown in Figure 6, keywords such as waste hierarchy, lifecycle, closed-loop supply chain, and resource efficiency are older in terms of the average publication year. On the other hand, keywords such as waste-to-energy, FW, bio-refinery, solid waste management, municipal waste, and developing country have been more recently paid attention to by scholars. Identifying the most recent active keywords within the waste management research area towards a CE can provide researchers with the research frontiers and most attractive investigation areas in this field.

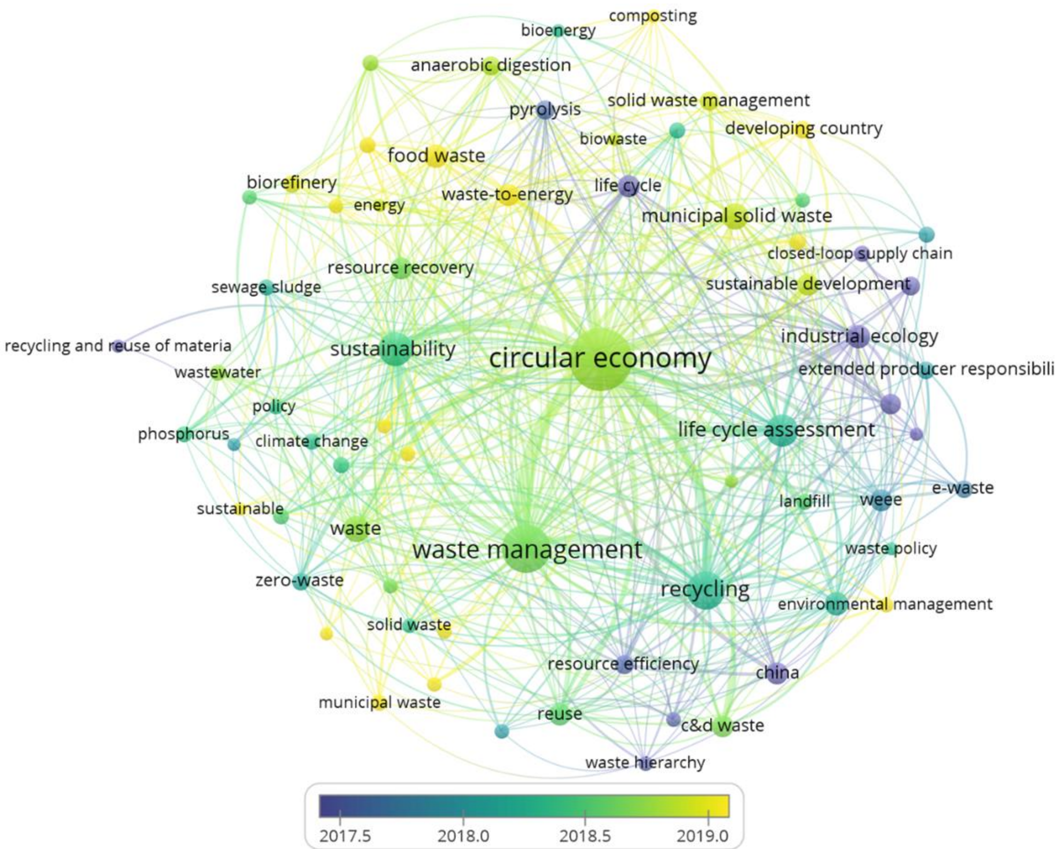


Figure 6. Co-occurrence network of the keywords.

2.4.2. Text mining results: discovering main research themes and trends

The obtained results in this section directly address the second research question:

- **RQ2.** What are the salient research themes and trends of waste management in the CE?

The text-mining results revealed that extant studies of waste management within the CE domain focus on seven key research themes, as shown in Table 3. The identified dominant themes, including (1) bio-based waste management, (2) CE transition, (3) E-waste, (4) municipal solid waste, (5) environmental impacts and lifecycle assessment, (6) plastic waste, and (7) construction and demolition waste management, are presented and discussed in this section.

Table 3. Salient research themes in waste management towards the CE.

No. and Label of the research theme	Main terms	Exemplary recent references
1. Bio-based waste management	Biochar, Bioeconomy, Bioenergy, Biofuel, Biogas production, Biomass, Biorefinery, Byproduct, Circular bioeconomy, Composting, FW, FW management, Organic Fraction of Municipal Solid Waste (OFMSW), Organic waste, Waste valorization	Imbert (2017), Tsai (2020), Zabaniotou and Kamaterou (2019), Loizia et al. (2019), Pérez-Camacho and Curry (2018), Cecchi and Cavinato (2019), Rekleitis et al. (2020), Kakadellis and Harris (2020), Elkhalifa et al. (2019)
2. CE transition	CE, Resource, Sustainability, Sustainable development, Circularity, Supply chain, Business model, Resource recovery, CE model, CE practice, CE strategy, Sustainable Development Goals, Industrial symbiosis, Recycle, Waste reduction	Shpak et al. (2020), Lu et al. (2020), Alvarez and Ruiz-Puente (2017), Okafor et al. (2020), Johansson and Henriksson (2020), Priyadarshini and Abhilash (2020)
3. E-waste	Behavior, Society, Government, E-waste, Consumer, Waste Electrical and Electronic Equipment (WEEE), Producer, Incentive, Manufacturer, Policymaker, Responsibility, Environmental protection, Waste	Sharma et al. (2020), Lu et al. (2015), Chen et al. (2020), Marke et al. (2020), Ottoni et al. (2020), Cole et al. (2019), Mayers et al. (2005)

	disposal, Extended Producer Responsibility, WEEE directive	
4. Municipal solid waste (MSW)	Policy, MSW, Waste generation, Municipality, European Union, Recycling rate, Waste hierarchy, Waste collection, Household waste, Biowaste, CE package, Packaging waste, Waste-to-energy, Secondary raw material, Separate collection	Malinauskaite et al. (2017), Kaza et al. (2018), Hadidi et al. (2020), Petryk et al. (2019), Smol et al. (2020), Abis et al. (2020), Morlok et al. (2017), Agovino et al. (2019), Valenzuela-Levi (2019), Siddiqi et al. (2020), Hadzic et al. (2018)
5. Environmental impacts and lifecycle assessment	Environmental impact, Landfill, Disposal, Emission, Incineration, Lifecycle assessment, Energy recovery, Climate change, Greenhouse gas emission, Environmental performance, Decision making, Recycling process, Material recovery, Environmental burden, Global Warming Potential	Thomsen et al. (2018), Jensen (2019), Peceño et al. (2020), Arushanyan et al. (2017), Boldoczki et al. (2020), Sandin and Peters(2018), Sauve and Van Acker (2020), Cortés et al.(2020), Zeller et al. (2020), Kouloumpis et al. (2020), Slorach et al. (2019), Gallego-Schmid et al. (2018)
6. Plastic waste	Recycling, Recovery, Plastic waste, Packaging, Chemical, Value chain, Human health, Threat, Prevention, Polymer, Rubber, End-of-Life, Recyclability, Contaminant, Single-use plastic	Sherwood (2020), Foschi and Bonoli (2019), Pazienza and De Lucia (2020), Andreasi Bassi et al. (2020), Leissner and Ryan-Fogarty (2019), Milios et al. (2018), Faraca and Astrup (2019), Eriksen et al. (2018), Eriksen et al. (2019)
7. Construction and Demolition (C&D) waste management	Technology, Raw material, Construction, C&D waste, Building, Concrete, Construction industry, C&D waste management, Sewage sludge ash, Industrial waste, Material efficiency, Slag, Steel, Energy consumption, Demolition	Kabirifar et al. (2020), Lederer et al. (2020), Jin et al. (2019), Esa et al. (2017), Li et al. (2020), Mahpour (2018), Smol et al. (2015), Mak et al. (2019)

Bio-based waste management has appeared as one of the leading research themes of waste management in the CE context. In this regard, FW management poses a significant challenge on the transition from a linear economy to a CE (Imbert, 2017). The studies related to this research theme mainly focus on valorization and turning FW into value-added resources and bioproducts (Imbert, 2017; Tsai, 2020; Zabaniotou and Kamaterou, 2019), optimization of energy production through anaerobic digestion in FW management (Loizia et al., 2019), using the anaerobic biorefinery to contribute to a regional bioeconomy (Pérez-Camacho and Curry, 2018), smart approaches to FW final disposal (Cecchi and Cavinato, 2019), waste biomass from the agricultural-livestock sector (Rekleitis et al., 2020), lifecycle assessment of bioplastic-based food packaging (Kakadellis and Harris, 2020), and FW to biochars through pyrolysis (Elkhalifa et al., 2019).

The second theme pertains to how a linear economy can be transitioned to a CE with a particular focus on waste management practices and activities. Due to the lack of a precise mechanism for collecting, sorting, and distributing waste, the transition to a CE will be long and complicated (Shpak et al., 2020). For instance, developing measurement and index systems (Lu et al., 2020), creating synergies and industrial symbiosis among industrial sectors based on the substitution of raw materials from waste, sub-products or recycled materials (Álvarez and Ruiz-Puente, 2017), end-of-life mismanagement and its profound negative ecological implications (Okafor et al., 2020), discursive framing of CE policies (Johansson and Henriksson, 2020), and energy recovery from waste (Priyadarshini and Abhilash, 2020) have been highlighted in the literature, as some of the main waste management challenges towards implementing a CE.

The significantly increasing demand for using electrical and electronic products across the globe has made proper E-waste management a top priority for developed and developing countries, particularly those in the CE transition phase (M. Sharma et al., 2020). E-waste is one of the most challenging subjects for policymakers in waste management since inappropriate E-waste treatment and recycling can hugely affect the environment and human health (Lu et al., 2015). Studies categorized in the E-waste research theme mostly investigate critical barriers and pathways to the implementation of E-waste formalization management systems (Chen et al., 2020), application of innovative circular business models to support E-waste reduction (Marke et al., 2020), E-waste valorization through developing adequate indicators for E-waste reverse logistics (Ottoni et al., 2020), solutions and incentives to move up on the top of the waste hierarchy in the E-waste treatment, rather than recycling (Cole et al., 2019), and the importance of modifying the E-waste directives and policy guidelines to ensure addressing all lifecycle impacts (Mayers et al., 2005).

The main research articles in the municipal solid waste theme mainly concentrate on the 3Rs (reduce, reuse, recycle) practices implementation to influence the behavior of citizens (Hadidi et al., 2020), proposing incentives for public engagement in the municipal solid waste management (Petryk et al., 2019), providing practical solutions for transformation towards a CE (Smol et al., 2020), increasing the collection rates of recyclables (Morlok et al., 2017), assessing the synergy between recycling and thermal treatments (Abis et al., 2020), factors influencing different collection rates and municipal recycling (Agovino et al., 2019; Valenzuela-Levi, 2019), waste-to-energy systems using municipal solid waste to produce energy (Siddiqi et al., 2020), and lifecycle assessment of solid waste management (Hadzic et al., 2018).

Through employing efficient waste management systems, the CE aims to increase resource efficiency and mitigate the environmental impacts of waste generation. Assessing the environmental implications of waste management practices has always been challenging to provide decision support for policymakers to make the optimal decisions regarding commitment to a clean and sustainable environment (Khoshnevisan et al., 2020). According to the text mining analysis results in the current study, the major challenges of environmental evaluation within waste management activities have been highlighted in the environmental impacts and lifecycle assessment theme. For example, environmental analysis of integrated organic waste and wastewater management systems (Thomsen et al., 2018), environmental assessment of different recycling processes (Jensen, 2019; Peceño et al., 2020), developing lifecycle assessment models for environmental assessment of possible future waste management scenarios (Arushanyan et al., 2017), measuring potential environmental benefits of preparation for reuse before recycling (Boldoczki et al., 2020), environmental impacts of textile reuse and recycling (Sandin and Peters, 2018), environmental impacts of municipal solid waste landfills (Sauve and Van Acker, 2020), environmental burdens of composting as a way to achieve a more circular waste valorization (Cortés et al., 2020), environmental consequences of CE options for biowaste flows (Zeller et al., 2020), plastic waste effects on climate change (Kouloumpis et al., 2020), environmental implications of recovering resources from FW in a CE (Slorach et al., 2019), and environmental impacts of the entire lifecycle of electrical and electronic waste (Gallego-Schmid et al., 2018), are some of the most critical environmental studies in this research theme.

Due to its extensive applications in industry and urban life, plastic has made waste management face various challenges and environmental concerns, from marine pollution to limited recycling. The main addressed subject areas of the plastic waste theme in the current study refer to closed-loop recycling of polymers (Sherwood, 2020), the interaction between plastic value chain stakeholders, and regulations towards implementing a CE (Foschi and Bonoli, 2019), defining a new plastics economy in the agriculture sector (Pazienza and De Lucia, 2020), extended producer responsibility for plastic packaging waste (Andreasi Bassi et al., 2020), challenges and opportunities for reduction of single-use plastics (Leissner and Ryan-Fogarty, 2019), identifying critical barriers for plastic recycling across the regional plastics value chain (Milios et al., 2018), evaluation of plastic recyclability (Faraca and Astrup, 2019), contamination in plastic recycling and the quality of reprocessed plastics (Eriksen et al., 2018), and circularity-potential assessment of recovery systems for household plastic waste (Eriksen et al., 2019).

Finally, construction and demolition waste generated throughout the construction cycle has been identified through the text mining analysis as the last research theme of waste management in the CE in the current study. Rapid urbanization in the world has increased construction and demolition waste (Kabirifar et al., 2020), which is considered one of the largest waste streams (Lederer et al., 2020). Sustainable treatment of construction and demolition wastes should be employed globally as an urgent social, environmental, and economic issue (Jin et al., 2019). In this regard, the scholars have paid close attention to developing strategies for managing construction and demolition wastes based on CE principles (Esa et al., 2017), application of information technologies in construction and demolition waste management (Li et al., 2020), prioritizing barriers to adopt CE in construction and demolition waste management (Mahpour, 2018), using sewage sludge ash in the construction industry as a way towards a CE (Smol et al., 2015), and behavior and attitudes towards recycling of construction and demolition waste in the community (Mak et al., 2019).

The revealed research themes of waste management practices towards a CE obtained from the text mining analysis on the abstracts of articles within the used dataset of this research allow mapping of how waste management subject areas have evolved over the years based on their average publication year. Figure 7 illustrates the timeline of dominant research themes and their waste management subject areas in the CE context over the recent five years. As shown in Figure 7, biochar, organic fraction of municipal solid waste, plastic waste, construction and demolition waste, FW, biofuels, circular bioeconomy, and single-use plastics have been attracting attention very recently, rather than material cycles, closed-loop supply chain, carbon emission, industrial ecology, and liquid waste.

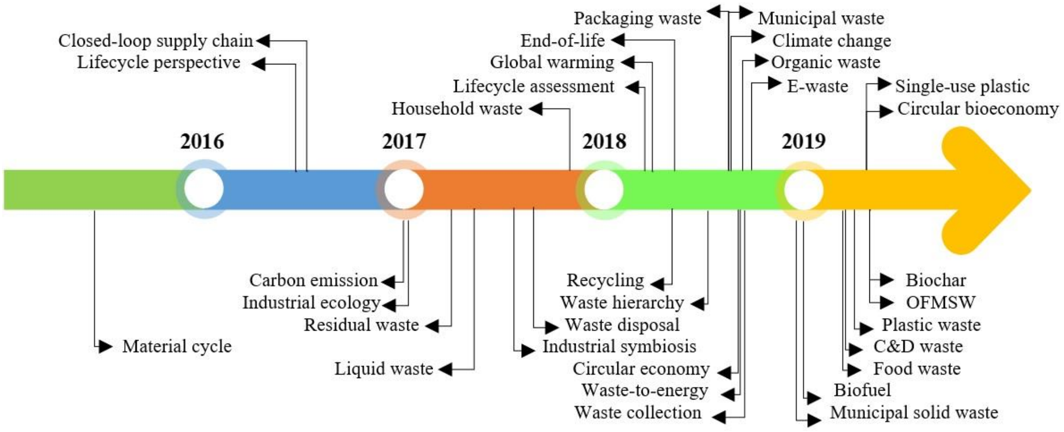


Figure 7. Timeline of dominant research themes and their waste management subject areas in the CE context.

2.4.3. Qualitative content analysis of the four clusters: more in-depth results

In addition to the text mining analysis provided in the previous section, the obtained results in this section also address the second research question:

- **RQ2.** What are the salient research themes and trends of waste management in the CE?

The data clustering of bibliographic coupling analysis revealed four main clusters of waste management research in the context of the CE (Figure 5 and Table 2). The fifteen most influential articles within each identified cluster from bibliographic coupling analysis (see section 2.4.1.4), including (i) CE perspectives on waste hierarchy, (ii) CE conceptualization and implementation, (iii) waste management within closed-loop supply chains, and (iv) CE approach to the waste management of plastics, are scrutinized to conduct the qualitative content analysis of the current study in this section.

2.4.3.1. Cluster 1: circular economy perspectives on the waste hierarchy

The fifteen most influential articles from the last two decades of research making up this cluster on " CE perspectives on the waste hierarchy" are relatively recent, including two articles published in 2015, two in 2016, five in 2017, two in 2018, and one in 2019. Journal of Cleaner Production, with six articles, has the largest representation in this cluster, followed by Journal of Industrial Ecology, and Bioresource Technology, with two articles each, and then Environmental Research Energy, Resources, Conservation & Recycling, Waste Management, and Journal of Environmental Management, with one article each. With different affiliations and coming from diverse countries, various authors are also noticed, with Iacovidou being the only lead author appearing two times within this cluster.

The first group of articles from this cluster can be drawn, including five articles sharing the "generic" feature, meaning their findings or the framework and tools they develop could be applied across sectors and businesses. While Van Ewijk and Stegemann (2016) discuss the barriers and potential solutions to take waste hierarchy to the next level for achieving absolute reductions in material throughput, the other authors from this group both question and develop the measuring and monitoring instruments (Iacovidou et al., 2017a) for waste management systems (Haupt et al., 2017) in a CE perspective (Iacovidou et al., 2017b). More recently, Nižetić et al. (2019) started to discuss the integration of smart technologies (e.g., smart cities and the Internet of Things) to achieve more sustainable management of resources and waste.

The second group of articles from this cluster is focused on industrial sectors of high interest. Among the ten articles from this group, multiple specific sectors of utmost importance for the future of enhanced waste management practices are highlighted: (i) waste treatment, including sewage sludge management solutions (Kacprzak et al., 2017; Smol et al., 2015), technologies for recovering phosphorus from municipal wastewater (Egle et al., 2015), glass recycling (Blengini et al., 2012), and waste electrical and electronic equipment at end-of-life (Mayers et al., 2005); (ii) textile reuse and recycling (Sandin and Peters, 2018); (iii) municipal solid waste (Malinauskaite et al., 2017) and sustainable urban planning for augmented resource management and valorization (Agudelo-Vera et al., 2011); and (iv) concrete examples of waste valorization following the waste hierarchy (Mata et al., 2018), such as specific lignocellulosic biorefineries converting biomass to bioethanol (Liguori and Faraco, 2016).

These articles challenge the waste hierarchy to move "from waste to resources" (Kacprzak et al., 2017) through concrete examples from the field. In fact, different but complementary CE principles and loops are recommended depending on the industrial sector. For instance, sewage sludge is increasingly seen as a valuable resource for energy generation (waste-to-energy) or use in the construction industry, e.g., as feedstock for cement or concrete production (Smol et al., 2015). Yet, these articles also highlight several gaps and margins for improvement to reach zero-waste systems, such as the need for developing more waste-to-energy plants and technologies (Malinauskaite et al., 2017) or the potential rebound effect and impact transfer caused by inefficient reverse supply chains to collect and reuse products (Sandin and Peters, 2018), necessitating optimized or better-dimensioned value chains.

2.4.3.2. Cluster 2: circular economy conceptualization and implementation

The majority of the articles from this cluster are literature review papers, both from a historical (Winans et al., 2017) and a geographical perspective (Ghisellini et al., 2016; McDowall et al., 2017; Su et al., 2013), as an attempt to conceptualize and clarify the CE (Merli et al., 2018; Reike et al., 2018), for which an advanced and more integrated waste management system is praised and required. According to the research conducted by Merli et al. (2018), waste management recently emerged as the most relevant sub-concept of the CE. In this line, the drivers and barriers of eco-innovation for enhanced waste management from a CE perspective have been analyzed by de Jesus and Mendonça (de Jesus and Mendonça, 2018).

The second group of articles from this cluster addresses the actual implementation of CE principles in diverse key businesses, e.g., in the building (including both the construction and demolition phases) industry (Gálvez-Martos et al., 2018), in the manufacturing industry (Lieder and Rashid, 2016), within industrial symbiosis (Dong et al., 2013) or the waste-to-energy supply chain for augmented CE systems (Kushairi et al., 2018; Pan et al., 2015). Discussions on the best practices from specific industries are particularly valued, such as in the building industry (Gálvez-Martos et al., 2018) with a particular interest in the management of construction and demolition waste through CE loops (Huang et al., 2018). Lastly, lessons learned from the implementation of CE principles within waste management systems are also highly valued by researchers and practitioners (Bachmann, 2007; Pan et al., 2015; Singh and Ordoñez, 2016).

2.4.3.3. Cluster 3: waste management within closed-loop supply chains

While waste mismanagement can lead to serious environmental issues, such as marine litter, air, soil, and water contamination, and hazardous waste leakage (Ferronato and Torretta, 2019), the implementation of a CE can improve current solid waste management activities in developing economies based on the principles of effective waste valorization and recycling (Ferronato et al., 2019). To achieve material efficiency and reduce virgin material and industrial waste volumes towards the CE transition, it is necessary to manage various barriers such as budgetary, information, management, employee, engineering, and communication within the supply chain (Shahbazi et al., 2016). An integrated waste management system benefits from a closed-loop supply chain and reverse logistics simultaneously (Islam and Huda, 2018; Pedram et al., 2017). The closed-loop supply chain approach integrates both forward and reverse supply chains with a particular focus on end-of-life products in the most environmentally friendly manner possible (Govindan and Soleimani, 2017).

The significant impact of product design in terms of modularity, reparability, and recyclability within the closed-loop supply chain network structure on the waste functions was highlighted by Krikke et al. (2003). In this regard, reuse at a module level was identified as the most beneficial recovery option, followed by material recycling and thermal disposal as the next best choices (Krikke et al., 2003). Sustainable optimal design and planning for chemical processes and supply chains focusing on energy efficiency and waste management to minimize waste and energy requirements and guarantee long-term sustainability is a significant challenge in supply chain management (Nikolopoulou and Ierapetritou, 2012). Besides, proper returns management not only in a specific stage but also in the full lifecycle of products, as a key driver of value creation rather than a cost of the business in closed-loop supply chains, can save the environment and support resource efficiency (Krikke et al., 2013). The application of online mobile platforms within the supply chain of municipal solid waste, where recycling practitioners or individuals can make appointments for on-site waste collection, was evaluated as beneficial by Gu et al. (2019) in terms of overall environmental performance for waste management systems. Effective designing of closed-loop supply chains under uncertainty is a highly complex and challenging task because of the interconnection of many factors such as product variety, the short lifecycle of products, increased outsourcing possibilities, and globalization of businesses (Vahdani et al., 2013). Lee and Chan (2009) developed an optimization model to minimize the total reverse logistics cost and high utilization rate of collection points for product returns, which improves the efficiency of logistics operations and supports reasonable recycling economically and ecologically. Moreover, a closed-loop supply chain network was designed by Özceylan et al. (2017) considering the end-of-life vehicles treatment, including reverse operations such as shredding, recycling, dismantling, and landfilling to reintegrating the reverse material flows into forwarding supply chains.

Recently, waste management systems have been facing the challenge of E-waste, as one of the main end-of-life products within the closed-loop supply chains, due to its severe adverse environmental and human health impacts. Policymakers and waste management practitioners dealing with E-waste should particularly consider all the disposition alternatives (i.e., recycling, remanufacturing, reuse and repair) in an integrated manner within the closed-loop supply chain network design (Islam and Huda, 2018). However, despite the increasing legal pressure on E-waste treatment policies, efficient E-waste management due to the lack of an effective collection system and public participation, as well as lax enforcement of regulations, is still in its infancy (Abdallah et al., 2012; Lu et al., 2015).

2.4.3.4. Cluster 4: the circular economy approach to plastic waste management

Increasing environmental concerns regarding the accumulation of plastic waste in the natural environment have pushed policymakers to develop renewable alternatives and suitable waste management strategies in recent years (Payne et al., 2019). The European Commission has strongly contributed to regulating production and consumption patterns on plastic and packaging in a CE to support sustainability along the entire plastic value chain from producers to waste collectors and recyclers (Foschi and Bonoli, 2019). Moreover, increasing the plastic recycling rate for both plastic packaging and plastic from household waste has been highlighted as a priority in the European Union's strategy towards a CE (Eriksen et al., 2018). Adopting a new plastic economy based on the CE principles, as an alternative to the linear economy, has gained momentum (Ellen MacArthur Foundation, 2016) to reduce plastic waste and mitigate its damage to the environment and wildlife. By applying a CE approach, plastic products are designed to be reused or recycled to reduce plastic leakage into the environment before waste mismanagement occurs (Jambeck et al., 2018). As an environmentally friendly alternative to fossil-based plastics, designing sustainable bioplastics opens up opportunities to reduce carbon footprint at the production level and overcome resource depletion by relying on the development of valorization protocols for renewable resources (RameshKumar et al., 2020).

Payne et al. (2019) highlighted the significant role of using chemical recycling instead of mechanical recycling for biodegradable plastics, such as polylactic acid, due to this approach's potential for further integration of polylactic acid into a CE. Faraca and Astrup (2019), in their study on plastic recyclability, highlighted the direct link between detailed characteristics of plastic waste and recycling and showed that the recyclability of "High Quality" plastic waste was 12–35% higher than "Low Quality" application. China's recent ban (late 2017) on imports of low-quality recyclates has significantly affected the waste management systems, which denotes the importance of quality of resources at different parts of the materials, components, and products characteristics lifecycle to facilitate the transitions towards resource efficiency (Iacovidou et al., 2019). Van Eygen et al. (2018) denoted that setting recycling targets for plastic packaging in line with the recycling process's actual output and maintaining the quality of the output product is necessary to (i) improve the circularity of plastic packaging and resource efficiency, and (ii) assess the performance of the waste management system accurately. Moreover, closing the plastic loop using mass-based recycling targets towards a CE transition is still challenging, and the focus of waste management strategies should be on decreasing impurities and losses through product design and technological advancements (Eriksen et al., 2019) and minimizing the material degradation during mechanical processes (Horodytska et al., 2018). The urgent need for regulating the standardized labeling and sorting instructions for waste management of bio-based plastics by governmental policymakers and material producers was outlined by Prieto (2016) to facilitate the CE transition. However, although the CE and sufficient recycling have been touted for managing plastic waste, over 50% of the plastic waste has been exported to hundreds of countries across the world, which denotes the necessity of adopting new policies to deal with the importation and exportation of plastic waste (Brooks et al., 2018). Besides, hazardous waste requires more managerial consideration for the circulation use of resources and increasing resource efficiency in developing a CE that targets waste reduction and turning waste into a resource (Koop and van Leeuwen, 2017; Sakai et al., 2011).

2.5. Conclusions

This study aimed to provide an inclusive map of waste management research in the context of the CE over the last two decades by (i) mapping the evolution of the field over time, and (ii) identifying the main research themes and trends. To achieve this, a mixed-method approach was followed by conducting bibliometric, text mining, and content analyses on a total of 962 peer-reviewed journal articles extracted from the Web of Science database, published from 2001 to 2020.

The obtained results unfolded four main clusters of waste management research in the CE context, including CE perspectives on waste hierarchy, CE conceptualization and implementation, waste management within closed-loop supply chains, and CE approach to Plastic waste management. Besides, seven dominant research themes of waste management practices within the CE context, including bio-based waste management, CE transition, E-waste, municipal solid waste, environmental impacts, and lifecycle assessment, plastic waste, and construction and demolition waste management, were identified. Subject areas, such as the organic fraction of municipal solid waste, plastic waste, construction and demolition waste, FW, biofuels, circular bioeconomy, and single-use plastics, have attracted attention very recently, rather than material cycles closed-loop supply chain, carbon emission, industrial ecology, and liquid waste.

The main findings of the present study shed light on the waste management research agenda and considerably contribute to the positioning of waste management activities and practices aligned with the CE principles in the future. The provided inclusive research landscape of waste management systems, and its prominent highlight patterns can serve as a base for a real-time guideline to lead further research areas and as a tool to support waste management policymakers and practitioners to support the CE transition (which aims to minimize the waste generation).

Chapter 3: Science Map of the Food Waste Research

3.1. Introduction

FW, representing a massive market inefficiency has posed severe challenges to the global economy, food supply chains, and agricultural and industrial systems. Approximately 1.3 billion tons/year, which represents one-third of all food produced, is never eaten and lost or wasted globally (Mirmohamadsadeghi et al., 2019), which calls all waste management sectors from collection to disposal to explore sustainable solutions (Girotto et al., 2015). Households and processing are the most contributing sectors to FW generation, accounting for more than 70 percent of the European Union's FW (Stenmarck et al., 2016). Moreover, the carbon footprint of food loss and waste is estimated to be 3.3 Gtonnes of CO_2, which makes food wastage rank as the third top emitter after the USA and China in the world (FAO, 2013).

The first step towards a more sustainable resolution to properly manage food surplus and FW is adopting a sustainable production and consumption culture (Papargyropoulou et al., 2014). FW generation covers the food lifecycle from agriculture at the beginning to industrial manufacturing and processing, retail, and household consumption (Mirabella et al., 2014). Although such an enormous amount of waste has raised serious waste management issues, it has brought some potential and opportunities to be treated, valorized, and reused into other production systems through biorefinery platforms (Carmona-Cabello et al., 2019, 2018; Mirabella et al., 2014). In this regard, FW, as a valuable resource with a high possibility to be used as a raw material for the production of chemicals, materials, and fuels (Lin et al., 2013), need to be paid attention to more intensively by waste-management authorities. Galanakis (2012) highlighted FW as a cheap source since the conversion technologies allow the recovery of high-added-value components from FW inside food chains as functional additives in a wide range of products.

FW, as one of the main streams of the generated bio-waste worldwide, has been widely addressed by research communities seeking pathways towards supporting a CE. FW biorefineries for biofuels and platform chemicals production can significantly reduce adverse environmental effects and support sustainable resource management in a circular bioeconomy paradigm (Tsegaye et al., 2021). Conducting a systematic review of FW conversion pathways, Santagata et al. (2021) outlined the opportunities for an emerging circular bioeconomy as (i) reduced environmental footprint and resource efficiency, (ii) avoided loss of economic value, and (iii) conditioning stakeholders' behavior. The individual bioprocesses in the waste biorefinery approach for FW, such as fermentation, acidogenesis, and methanogenesis, need to be optimized for generating various bio-based products and better transforming linear economy to a circular bioeconomy (Dahiya et al., 2018). Future technological advances in FW management are expected to capitalize on the multi-functionality of products, boundaries, trade-offs between resources and FW, and allocation in a circular system (Mak et al., 2020).

Due to the wide range of FW research, considering different perspectives from technological advancements in waste recovery and biofuel production to consumption behavior and cultural issues, the literature in this area is very fragmented. As a result, a comprehensive knowledge map of the FW literature is still lacking. Therefore, this part of the current thesis aims to fill this gap by providing a systematic bibliometric review of the available scientific production in the FW arena. The provided insights in this part contribute to the existing studies by providing state-of-the-art of FW research, in particular by (i) presenting the performance indicators of scientific production in the target literature to date, (ii) mapping theoretical and practical developments within the FW research in the context of transitioning from a linear economy to a CE, and (iii) identifying the main areas of research, hotspots, and research tendencies in the FW sector. To this end, a systematic bibliometric analysis is conducted considering keywords, and bibliographic coupling networks as the main units of analysis to address the following research questions:

- **RQ1.** How has scientific production in FW research developed over time?
- **RQ2.** What are the seminal research hotspots (keywords) building the FW literature?
- **RQ3.** What are the major emergent subject areas of research in the FW domain?

3.2. Materials, methods, and research design

A systematic bibliometric review analysis adapted from Belussi et al. (2019) and Ranjbari et al. (2022, 2021a) was performed in this study to provide the state-of-the-art of FW potentials and applications in the target literature. The bibliometric analysis evolved in three steps: (1) descriptive bibliographic analysis to present the publication performance in terms of time distribution, sources, contributing countries and institutions, and funding agencies, (2) keyword-based analysis to identify research hotspots and tendencies, and (3) bibliographic coupling analysis of the articles to map the core emergent research areas of the most recent studies within the FW literature. Figure 8 visualizes the overall research design and employed methods in this study corresponding to the relevant research questions. The defined search strategy to collect the most relevant data as well as methods of analysis are described in the following sub-sections.

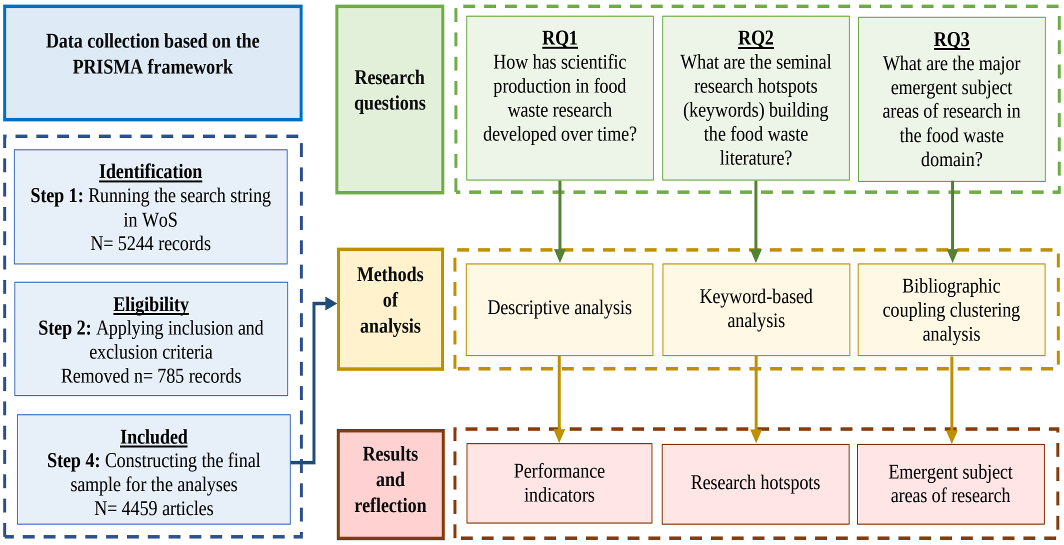


Figure 8. The review framework.

3.2.1. Search strategy and data collection

A search protocol based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (Liberati et al., 2009) was developed to systematically identify, screen, and select relevant articles from the target literature. In this vein, the Web of Science Core Collection, as the world's most trusted global citation database, was used as this research database. Given the main focus of this research, different combinations of the main keyword "food waste" were tested. As a result, the following search string including AND/OR operators was constructed: "food wast*" OR "wast* of food" OR "wast* food". The initial run of the search string on the title of the articles in Web of Science returned a total of 5244 articles.

In the next step, the results were limited to only (i) peer-reviewed articles, (ii) journal articles, and (iii) English materials. On this basis, proceeding papers, meeting abstracts, editorial materials, news items, book reviews, corrections, book chapters, letters, and notes were excluded from the data sample. Nevertheless, no time-period limit was applied to cover all scientific production within the study area. Moreover, the continuous process of capturing data was stopped by adding the last update on December 25, 2022, to the dataset. Consequently, 4459 articles published from 1985 to 2022 remained as the final sample for further consideration in this study. The details of the search strategy and the article selection process are tabulated in Table 4.

Table 4. The search protocol to collect data from the target literature.

Search string	"food wast*" OR "wast* of food" OR "wast* food"
Searched in	Title of the documents
Database	Web of Science
The last update	December 25, 2022
First Result	5244 documents
Inclusion criteria	(i) English documents, and (ii) peer-reviewed journal articles and reviews
Final sample	4459 articles
Latest update	25/12/2022

3.2.2. Analysis methods: clustering and data representation

Researchers have widely employed bibliometric analysis as a quantitative technique and powerful statistical tool to evaluate the scientific production performance and map a body of knowledge in various fields and domains. The bibliometric approach to reviewing the literature, with a special focus on the links among influential articles, contributing authors, main sources, references, and citation and co-citation networks (Grosseck et al., 2019), supports presenting an inclusive overview of the target literature. Moreover, bibliometric techniques increase researchers' analytical ability by introducing objective measures for scientific productions assessment that contrast the potential bias embedded in subjective assessments (Appio et al., 2014).

Bibliometric analysis has assisted researchers in dealing with numerous publications in the waste management research arena towards a CE. Accordingly, various research teams have quantitatively analyzed and mapped the development of different lines of waste management in the CE on a broader outlook, such as municipal solid waste management (Tsai et al., 2020), waste incineration (Xing et al., 2019), and construction and demolition waste (Wu et al., 2019).

In this review, two analyses are performed on the collected articles. First, a descriptive analysis is carried out on a total of 4459 peer-reviewed articles collected from the Web of Science database to provide performance indicators of scientific production in the FW domain. Second, a bibliometric analysis is conducted by following two bibliometric approaches, including (i) the keyword-based approach and (ii) the citation-based approach.

The keywords of the articles in the sample are analyzed and mapped based on their occurrence, co-occurrence, and recentness to render a general overview of the research field's tendencies and hotspots. Scholars have benefited significantly from keyword-based analysis as a useful knowledge-mapping tool for unfolding the conceptual and thematic structure of academic domains and disciplines (Krey et al., 2022). Keywords co-occurrence analysis considers keywords as nodes, and the co-occurrence of a pair of nodes represents a link between those nodes in the keywords co-occurrence network constructed. In this context, the number of times that a pair of author keywords (nodes) co-occurs specifies the weight of the relevant link (Radhakrishnan et al., 2017).

Among the citation-based approaches in bibliometric analysis, bibliographic coupling analysis is considered one of the main and most accurate bibliographic techniques to assess the links between two scientific documents (Belussi et al., 2019). Therefore, a bibliographic coupling analysis is used to study the possible relationship between scientific publications in the FW context. The bibliographic coupling link strength between two objects denotes the number of times these two objects have simultaneously cited another object. On this basis, the bibliographic coupling analysis, with a forward-looking perspective in analyzing the literature (Belussi et al., 2019), is used to cluster the collected articles based on the bibliographic coupling links to identify more recent research areas within the FW literature.

The VOSviewer software version 1.6.16 (van Eck and Waltman, 2010) is used to perform the analysis. VOSviewer is a computer program developed in the Java programming language that explores and visualizes node-link maps within documents based on bibliographic data (Su et al., 2021; van Eck and Waltman, 2010). Each node-link in the map denotes a bibliometric network of an object in the database, such as keywords, articles, or references, which extensively assists with better understanding and analyzing the research trends of a specific discipline (Su et al., 2021).

3.3. Descriptive analysis results: performance indicators

The provided results in this section address the first research question:

- **RQ1.** How has scientific production in FW research developed over time?

3.3.1. Publications' evolution over time

To provide an insight into the evolution of publications considering FW over time, the trend of publication of the articles and their citations in the considered sample dataset is plotted in Figure 9. This figure shows the scientific publication trend of research on FW covering the period from 1985 to 2022. As can be seen, starting from 2004, the total number of publications started to increase, and despite fluctuations until 2010, continued its growth with the sharpest increase in 2018. Therefore, the main research period in terms of active academic involvement in the research area can be considered from 2010 to today. Although the number of publications in 2022 is lower than but very close to that of 2021 (773 vs. 787), this cannot be considered as a decrease in publications, as the data has been gathered in

December 2022, when more publications may be registered in the remaining period of the year. The number of annual citations has also followed an increasing trend starting from 2006, except in 2022, where the time period considered (until December 25th) is shorter than the other years.

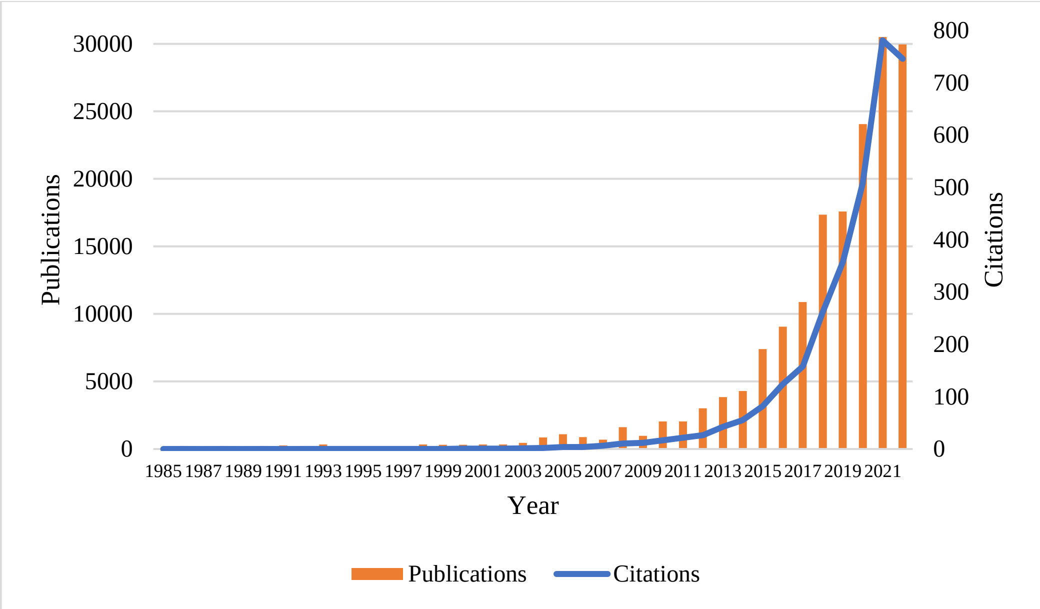


Figure 9. Annual published articles and citations in the research field of FW.

3.3.2. Journals and publishers

In total, 232 publishers have contributed to the publication of the 4459 articles in the studied dataset. The seven most contributing publishers (i.e., Elsevier, MDPI, Springer Nature, Taylor and Francis, Wiley, Sage, and Emerald Group Publishing) account for 83% of the published articles (3678 articles of the total), as shown in Figure 10. Moreover, while the selected sample of articles was distributed in 781 journals, 45% of them (2008 articles) were published in only 15 journals. More than 70% of the journals (i.e., 547 journals) published only one or two articles in the studied field.

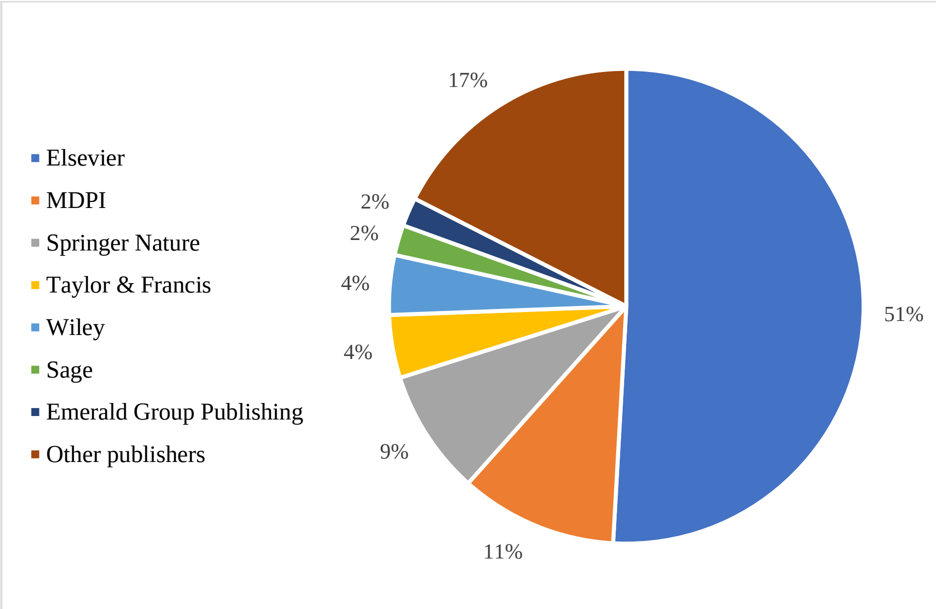


Figure 10. The main contributing publishers in the publication of FW-related research.

Table 5 provides the list of 15 journals that have published the highest number of articles in the studied dataset. As can be seen in this table, "Bioresource Technology", "Journal of Cleaner Production", and "Waste Management" are the three most productive journals with 513, 272, and 253 articles, respectively. Although these three journals have also received the highest number of citations to their articles, the highest average citation per article (AC) (i.e., 58.4) is earned by "International Journal of Hydrogen Energy". Furthermore, the average publication year (APY) reported in Table 2 shows that among the listed journals, "Foods", and "Sustainability" both published by MDPI have been more active in the publication of more recent articles rather than the older ones.

Table 5. The top 15 publishing journals in the field of FW research.

Rank	Journal	No. of articles	Share of the total sample	Citations	AC*	APY*
1	Bioresource Technology	513	11.51%	24929	48.6	2017.69
2	Journal of Cleaner Production	272	6.1%	10719	39.4	2019.30

3	Waste Management	253	5.67%	12774	50.5	2016.94
4	Sustainability	208	4.67%	2671	12.8	2020.33
5	Resources, Conservation and Recycling	113	2.53%	5424	48	2018.75
6	Science of the Total Environment	111	2.49%	3468	31.2	2019.56
7	Journal of Environmental Management	97	2.18%	2911	30	2018.81
8	International Journal of Hydrogen Energy	71	1.59%	4149	58.4	2015.30
9	Waste Management Research	61	1.37%	1559	25.6	2014.64
10	Environmental Science and Pollution Research	57	1.28%	665	11.67	2019.32
11	British Food Journal	55	1.23%	1184	21.53	2019.25
12	Energies	55	1.23%	529	9.62	2019.82
13	Waste and Biomass Valorization	49	1.1%	630	12.86	2019.16
14	Foods	47	1.05%	475	10.11	2021
15	Chemosphere	46	1.03%	987	21.46	2019.63

*AC: Average citation per article; APY: Average publication year

3.3.3. Thematic research categories in Web of Science

Based on the Web of Science classification, the collected articles are published in 135 research categories. Figure 11 presents the top 20 Web of Science research categories in terms of the number of published articles in the FW study area. Since a single article may belong to more than one research category, the sum of the numbers shown in Figure 11 exceeds the number of articles in the dataset. As can be seen in this figure, approximately 40.48% of the articles (1805 out of 4459) are classified in the "Environmental Sciences" category. Having "Engineering Environmental", and "Environmental Studies" in the 2nd, and 9th ranks highlights the concern of authors in the context of FW research towards the environmental issues linked with this field of study. On the contrary, the categories "Business" and "Management" appeared in the 12th and 16th ranks, accounting for 2.49% and 1.73% of the published articles, respectively, highlighting the less attention to the business and managerial issues within the FW sector compared to other technical and environmental aspects. Moreover, "Multidisciplinary Sciences" with a total of 75 published articles denotes the increasing attention to the multidisciplinary approaches in dealing with FW management practices.

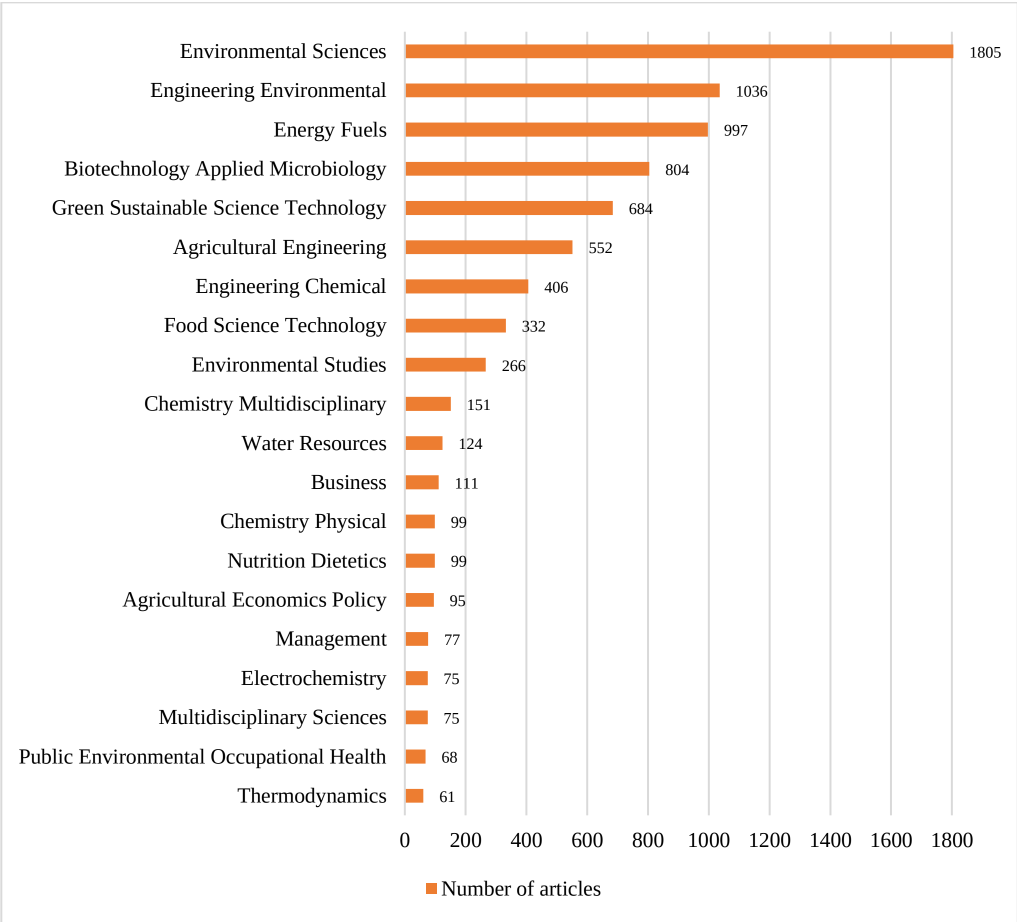


Figure 11. The top 20 Web of Science thematic research categories in FW research.

3.3.4. Geographical distribution of contributions

A total of 111 countries contributed to the production of scientific literature on the FW domain. The top 10 countries in terms of the number of published articles are presented in Table 6. As can be seen, China, the USA, and South Korea, with 1241, 549, and 367 articles, respectively, are the top three productive countries, publishing overall 48.37% of the articles. These countries also have the highest citation numbers compared to the other countries on the list.

Table 6. The top 10 contributing countries in terms of the number of published articles in the FW domain.

Rank	Country	No. of articles	% of total articles	Total citation	No. of collaborating countries	Total international collaboration	Average publication year
1	China	1241	27.83	34452	61	633	2018.90
2	USA	549	12.31	15118	50	311	2017.63
3	South Korea	367	8.23	12522	42	202	2015.74
4	Italy	328	7.35	10280	50	238	2019.09
5	England	300	6.73	13832	62	343	2018.36
6	India	282	6.32	6076	47	210	2019.49
7	Australia	202	4.53	4975	41	174	2019.07
8	Japan	190	4.26	5728	23	146	2016.20
9	Canada	160	3.59	4595	28	86	2015.97
10	Spain	146	3.27	5374	39	113	2018.13

Considering the international collaborations among the contributing countries, China with 663 international collaborations with 61 partner countries in their published articles is the leading country in international co-authorship in FW research. Table 7 provides the most frequent pairs of countries co-authoring articles in the FW arena based on the dataset used in this research. The most frequent international collaboration has taken place between China and Japan, referring to

73 collaborations. This regular collaboration is followed by the co-authorship among China and USA, China and England, and China and Singapore with the frequency of 68, 51, and 51, respectively. Among the 10 pairs of countries in Table 7, China has appeared in 8 pairs, and the USA and South Korea each in 2 pairs. Notably, these countries are also the top 3 countries in terms of the number of publications, according to Table 6.

Table 7. The top 10 collaborating pairs of countries in FW research.

Country 1	Country 2	No. of collaborations
China	Japan	73
China	USA	68
China	England	51
China	Singapore	51
China	India	41
China	Australia	37
USA	South Korea	36
China	South Korea	35
England	Netherlands	25
China	Canada	24

Furthermore, among the institutions within the contributing countries, Chinese Academy of Science, Tsinghua University, and Tongji University, all from China, with 115, 107, and 63 articles, respectively, are the top three contributing institutions to the topic, as shown in Table 8. Notably, all the top 10 contributing institutions to FW research belong to East Asia, while Europe and America have no institutions in this list.

Table 8. The top 10 contributing institutions in terms of the number of published articles in the FW domain.

Organizations	Country	Articles	% of total articles
Chinese Academy of Science	China	115	2.579
Tsinghua University	China	107	2.4
Tongji University	China	63	1.413
University of Science & Technology Beijing	China	60	1.346
Hong Kong Baptist University	Hong Kong	58	1.301
Zhejiang University	China	57	1.278
Tohoku University	Japan	56	1.256
National University of Singapore	Singapore	55	1.233
Shanghai Jiao Tong University	China	55	1.233
Korea Advanced Institute of Science & Technology Kaist	South Korea	54	1.211

Several funding agencies have supported studies conducted in the field of FW to encourage research in this domain. Among the 4459 articles in the dataset of this review, 3164 articles (i.e., approximately 71% of the total articles) have received funding support from at least one funding agency. Table 9 provides a list of highly supporting funding agencies regarding the number of articles they have supported. Approximately 11.57% of the total articles (516 out of 4459 articles) are supported by the National Natural Science Foundation of China, leading this organization to be the highest supportive funding agency in FW-related research. The next ranks refer to European Commission and Fundamental Research Funds for The Central Universities with 126 and 101 articles, respectively. As can be seen from Table 9, the National Natural Science Foundation of China has a significant distance from the other funding organizations in terms of the number of articles supported. The number of articles supported by the European Commission is more than three times the number of articles funded by its following organizations, showing the potential of this institution in supporting research within the FW research field.

Table 9. The most supportive funding agencies in the research field of FW.

Funding Agency	Number of articles	% of total articles
National Natural Science Foundation of China (NSFC)	516	11.572
European Commission	126	2.826
Fundamental Research Funds for The Central Universities	101	2.265
National Key Research and Development Program of China	94	2.108
Uk Research Innovation (UKRI)	76	1.704
National Research Foundation of Korea	63	1.413
China Postdoctoral Science Foundation	59	1.323
China Scholarship Council	54	1.211
National Key R&D Program of China	53	1.189
National Science Foundation (NSF)	51	1.144

3.3.5. Influential articles

As derived from the study of Merigó et al. (2015), the number of citations to a paper can be considered a suitable metric for recognizing the most influential articles in a research area. Hence, considering highly cited articles as more influential in the research field, Table 10 presents the top 10 most influential research and review articles in the field of FW within the dataset of this research. In this table, the collected articles have been ranked based on the global citation score, which refers to the total citations received by an article in the Web of Science database.

According to Table 10, the three most influential articles are review articles published in Philosophical Transactions of the Royal Society B-Biological Sciences, Renewable & Sustainable Energy Reviews, and Trends in Food Science & Technology with 1449, 734, and 723 citations in the Web of Science database, respectively. In this vein, the most influential article published by Parfitt et al. (2010), highlights the quantification and potential of FW within food supply chains for change to 2050. In the 2nd highly cited review paper, having studied anaerobic digestion, as an effective solution for FW treatment and valorization, Zhang et al. (2014) reviewed the FW characteristics, anaerobic digestion principles, the process parameters, and pretreatment and co-digestion approaches for enhancing anaerobic digestion of FW. Conventional and emerging technologies as well as commercialized applications in the recovery of high-added-value components from FWs were reviewed in the 3rd highly cited review conducted by Galanakis (2012).

Two out of the 10 highly cited research articles were published in Journal of Cleaner Production and are ranked 5th, and 8th, earning 641, and 482 citations, respectively. Notably, this journal was ranked 2nd among the most contributing journals to FW research in terms of the number of published articles, as shown in Table 2. In this regard, Papargyropoulou et al. (2014) outlined the importance of adopting a sustainable production and consumption approach to effectively tackle food surplus and waste issues towards a more sustainable FW management in the global food supply chain. Schanes et al. (2018) in a systematic review of household FW practices showed that (i) FW is a multi-faceted and complex issue that cannot be linked to a single line of practice or research, calling for a holistic integration of various disciplinary perspectives, and (ii) understanding of household practices affects the determinants of waste generation and also FW prevention strategies.

In the 4th influential research, an inclusive image of the most innovative uses of food supply chain waste as a valuable resource in producing various chemicals, materials, and fuels was presented by Lin et al. (2013). In their study, they suggested focusing on the valorization and re-use strategies for the 2nd generation of FW rather than conventional FW processing to use the FW potential as a sustainable raw material. In the 7th highly cited research, Kummu et al. (2012) studied the global food supply chain loss and its impact and outlined that approximately 25% of the produced food is lost within the food supply chain, for which 23% of the total global fertilizer use, 24% of the total freshwater resources used in food crop production, and 23% of the total global cropland area has been spent. The 9th influential research refers to the study conducted by Stancu et al. (2016) in examining the impacts of psycho-social factors, food-related routines of consumers, and household perceived capabilities on self-reported FW. In this study, it was proved that "perceived behavioral control and routines related to shopping and reuse of leftovers are the main drivers of FW while planning routines contribute indirectly. In turn, the routines are related to consumers' perceived capabilities to deal with household-related activities". Moreover, in the 10th highly cited research, Quested et al. (2013) in a study on the FW behavior showed that FW prevention has less visibility than many other pro-environmental behaviors, such as recycling, and accordingly, social norms around FW are less critical than more visible activities.

Table 10. The top 10 most cited articles in the FW research.

Ref.	Title	Journal	Citation	Type
(Parfitt et al., 2010)	Food waste within food supply chains: quantification and potential for change to 2050	Philosophical Transactions of the Royal Society B-Biological Sciences	1449	Review
(Zhang et al., 2014)	Reviewing the anaerobic digestion of food waste for biogas production	Renewable & Sustainable Energy Reviews	734	Review
(Galanakis, 2012)	Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications	Trends in Food Science & Technology	723	Review

(Lin et al., 2013)	Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective	Energy & Environmental Science	675	Article
(Papargyropoulou et al., 2014)	The food waste hierarchy as a framework for the management of food surplus and food waste	Journal of Cleaner Production	641	Article
(Zhang et al., 2007)	Characterization of food waste as feedstock for anaerobic digestion	Bioresource Technology	628	Article
(Kummu et al., 2012)	Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use	Science of the Total Environment	624	Article
(Schanes et al., 2018)	Food waste matters - A systematic review of household food waste practices and their policy implications	Journal of Cleaner Production	482	Review
(Stancu et al., 2016)	Determinants of consumer food waste behaviour: Two routes to food waste	Appetite	439	Article
(Quested et al., 2013)	Spaghetti soup: The complex world of food waste behaviours	Resources, Conservation and Recycling	430	Article

3.4. Keyword-based analysis results: Research hotspots

The results obtained from keyword-based analysis in this section address the second research question:

- **RQ2.** What are the seminal research hotspots (keywords) building the FW literature?

To discover the main idea and the scope of articles within the FW domain, keyword co-occurrence analysis is conducted on the authors' keywords in this section. After a proper data cleaning on the identified 8872 author keywords, 8355 unique keywords remained. Among these keywords, 740 keywords had more than 3 occurrences, which were used for further analysis through building the co-occurrence network of keywords in Figure 12. In order not to lose time overlay information, for the early access articles that were not assigned to any journal issue (i.e., had no publication year specified), the year 2023 was considered as their publication year.

Figure 12 presents two versions of the keywords' co-occurrence network; the first one shows an overview of the theme of the keywords by clustering them into two groups and the second one illustrates the time overlay of the keywords. This figure provides five main categories of information regarding the author’s keywords. First, it shows the keywords with at least 4 occurrences in the network's nodes. Second, it reflects the frequency of appearing the keywords through the size of their corresponding nodes, such that a larger node represents a higher occurrence of the targeted keyword. Third, the co-occurrence of the keywords is shown in the network by the lines linking the nodes. Fourth, the thickness of the lines between the nodes indicates the number of co-occurrences of the pair of nodes, such that a thicker line illustrates a more frequent co-occurrence. And finally, the colors of the nodes in the clustering version of this figure show the two identified clusters and the color range in the time overlay version of the figure shows the recentness of the keywords, such that the darker the color of the node, the older its average publication year. The average publication year refers to the mean of the publication year of all articles, including a specific keyword among their authors’ keywords.

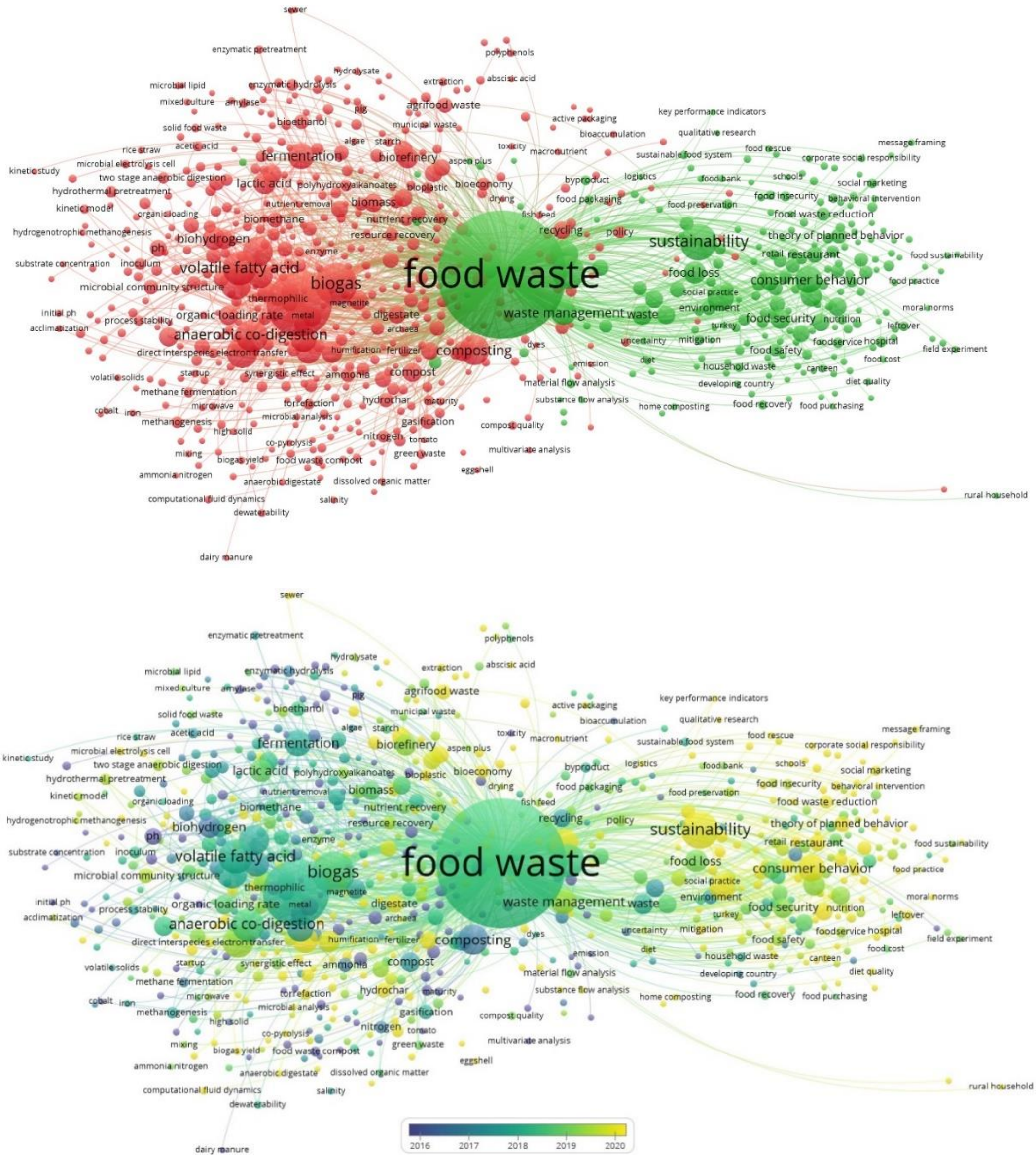


Figure 12. Co-occurrence network of authors' keywords in the research field of FW-identified clusters of keywords (up) and time overlay of keywords (down).

As can be seen in the upper part of Figure 12, based on the keywords mapped on the co-occurrence network, the authors' keywords mainly follow two themes, including (i) technical aspects of FW recovery and valorization, and (ii) and non-technical aspects of FW generation and management. Although FW with 2443 occurrences is a common keyword in both themes, as its co-occurrence with the keywords in the cluster of non-technical aspects of FW is higher, this keyword has been assigned to the green cluster. Table 11 provides key information about these themes to facilitate the comparison among them. As can be seen in this table, the number of keywords in the red cluster is higher than that of the green one, which is in line with the higher number of articles published in this theme. However, the higher average publication year of the keywords located in the green cluster indicates that the attention to FW topics from the non-technical perspectives is more recent in comparison with the technical aspects. This recentness can also be captured from the time overlay presented in Figure 12.

Table 11. Key information of the co-occurrence network of authors' keywords in the research field of FW.

	Red cluster	**Green cluster**
Focus	Technical aspects of FW recovery and valorization	Non-technical aspects of FW generation and management
Number of keywords	515	225
Average publication year of the keywords	2018.1	2018.9
Oldest keyword (based on average publication year)	leachate (2004.9)	life cycle inventory (2012.75)
The top three most recent keywords (based on average publication year)	metagenomic analysis (2022.25); co-composting (2022); food byproduct (2021.667)	supply chain management (2022); livestock (2021.75); moral norms (2021.75)
Top 20 most frequent keywords (occurrences in parentheses)	anaerobic digestion (580); biogas (238); volatile fatty acid (146); anaerobic co-digestion (133); co-digestion (120); microbial community (118); methane (114); composting (111);	FW (2443); sustainability (175); life cycle assessment (142); CE (103); consumer behavior (88); household FW (87); waste management (82); food loss (59); household (55); waste

	fermentation (84); sewage sludge (83); biochar (82); hydrogen (80); biohydrogen (62); lactic acid (59); pyrolysis (56); biorefinery (53); municipal solid waste (49); organic loading rate (46); organic waste (44); methane production (43)	(50); food security (47); environmental impact (41); consumer (40); food (37); COVID-19 (36); food supply chain (36); plate waste (34); restaurant (32); greenhouse gas emission (31); theory of planned behavior (29)

The co-occurrence of the keywords shown in Figure 12 as the links connecting a pair of nodes can deepen the insight into the approaches taken by the authors in the articles. Table 12 provides a list of 20 pairs of keywords with the highest link strength (i.e., the highest number of co-occurrences). As can be seen, the keyword "food waste" has the highest number of links with other keywords. The top 5 highest link strengths refer to the link between the keyword "food waste" and the keywords "anaerobic digestion" (419 co-occurrences), "biogas" (151 co-occurrences), "sustainability" (120 co-occurrences), "volatile fatty acid" (99 co-occurrences), and "anaerobic co-digestion" (96 co-occurrences). Four of these keywords belong to the technical aspects of FW recovery and valorization, and only "sustainability" is linked with non-technical aspects of FW generation and management. Furthermore, most of the keyword pairs mentioned in this table are related to the technical aspect of FW recovery, with a specific focus on digestion and valorization of FW, highlighting the huge number of studies on these topics.

Table 12. The top 20 most frequent pairs of keywords.

Keyword 1	Keywords 2	Link strength
FW	anaerobic digestion	419
FW	biogas	151
FW	sustainability	120
FW	volatile fatty acid	99
FW	anaerobic co-digestion	96
anaerobic digestion	biogas	95
FW	life cycle assessment	93
FW	microbial community	83
FW	methane	79
FW	co-digestion	76
FW	composting	66
FW	consumer behavior	66
FW	sewage sludge	65
FW	hydrogen	63
FW	CE	58
FW	biochar	55
FW	fermentation	55
FW	household	49
anaerobic digestion	methane	48
FW	food loss	46

3.5. Bibliographic coupling analysis results: discovering emergent research areas

The results obtained from bibliographic coupling analysis in this section address the third research question:

- **RQ3.** What are the major emergent subject areas of research in the FW domain?

To provide a map of the emergent research themes, the bibliographic coupling analysis was conducted on the articles in the studied sample. In this regard, articles were clustered based on bibliographic coupling links (i.e., the number of references they shared). To this end, to capture the most recent research themes only publications from 2018 onwards (i.e., the last 5 years) were considered. Moreover, review articles were removed from the dataset, as they share several links with the articles and affect clustering. Consequently, 2803 articles out of 4459 articles remained in the studied dataset. Among the remaining articles, 26 articles shared no references with other articles, and therefore, they were removed from the clustering process. As a result, the remaining 2777 articles formed three clusters, as illustrated in Figure 13, and reported in Table 13. These three identified clusters represent the major emergent research areas in the FW literature, including (i) technological developments in FW treatment systems and biorefinery applications, (ii) FW supply chain management towards a CE: sustainability and environmental concerns, and (iii) FW behavior and consumption patterns. These FW research themes are described in the following sub-sections.

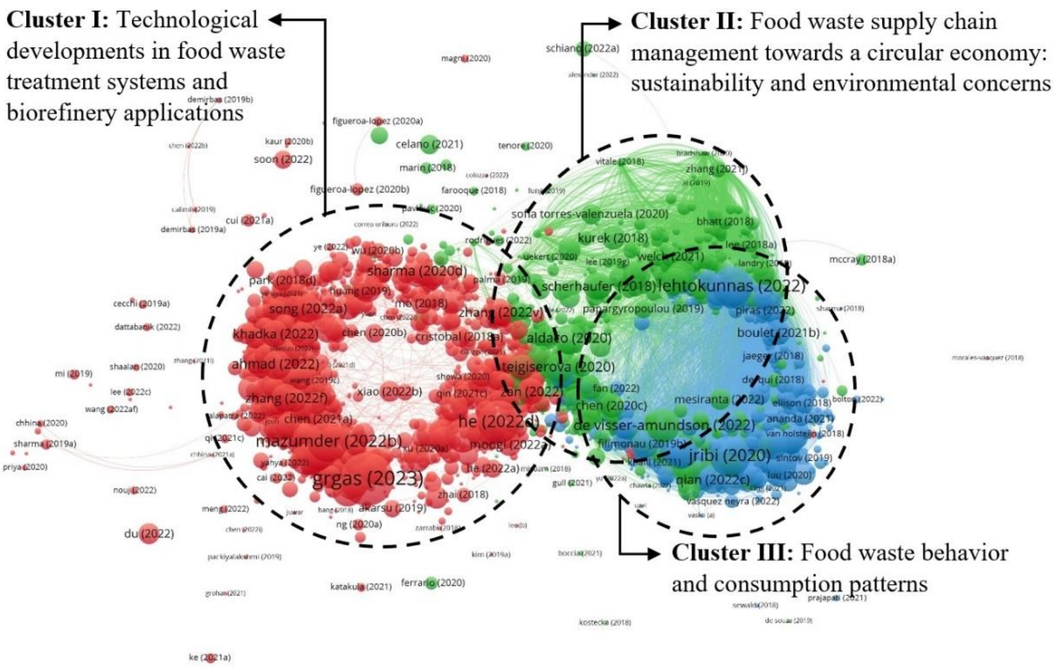


Figure 13. Bibliographic coupling clustering: emergent research areas in the FW literature.

Table 13. Bibliographic coupling clusters of FW-related research articles.

Cluster name	Number of articles	Sample articles
Cluster I: Technological developments in FW treatment systems and biorefinery applications	1721	(Mohanty et al., 2022), (M. Du et al., 2021), (Liu et al., 2022), (Mazumder et al., 2022), (Zhang et al., 2022), (Zan et al., 2022), and (P. Sharma et al., 2020).
Cluster II: FW supply chain management towards a CE: sustainability and environmental concerns	587	(Caldeira et al., 2019), (Slorach et al., 2019), (Tonini et al., 2018), (Malefors et al., 2022), (Scherhaufer et al., 2018), (Al-Obadi et al., 2022), (de Visser-Amundson, 2022), and (Corrado and Sala, 2018).

Cluster III: FW behavior and consumption patterns	469	(Brizi and Biraglia, 2021), (Lehtokunnas et al., 2022), (Bravi et al., 2020), (Di Talia et al., 2019), (Qian et al., 2022), (Li et al., 2021), (Amicarelli and Bux, 2021), (Everitt et al., 2022), and (Boulet et al., 2021).

3.5.1. Cluster I: technological developments in food waste treatment systems and biorefinery applications

The highest number of articles (N=1721) have appeared in this cluster, highlighting technological advancements and biorefinery applications in FW treatment systems. Due to the global attention to shift towards sustainable development, FW biorefineries have recently gained momentum because of their capabilities in producing biofuels and bio-based materials from FW valorization (Tsegaye et al., 2021). Hence, many research activities have been carried out to study the characteristics, applications, and implications of FW biorefineries for implementing a circular bioeconomy. The FW biorefinery approach should be optimized regarding the cascade of individual bioprocesses for transitioning from a linear economy to a circular bioeconomy (Dahiya et al., 2018).

In this regard, the major topics of research have been conversion of FW to energy with a focus on lifecycle assessment and sustainability (Liu et al., 2022; Mohanty et al., 2022; Sridhar et al., 2021), high-value FW and food residues biorefineries focusing on unavoidable wastes from processing (Teigiserova et al., 2019), techno-economic and profitability analysis of FW biorefineries (Cristóbal et al., 2018; Mazumder et al., 2022), energy production through anaerobic digestion of FW (Loizia et al., 2019; Zhang et al., 2022), microbial production from FW (P. Sharma et al., 2020; Song et al., 2022), FW valorization through co-composting (Ravindran et al., 2022), smart approaches to FW final disposal (Cecchi and

Cavinato, 2019), lifecycle assessment of bioplastic-based food packaging (Kakadellis and Harris, 2020), FW to biochars through pyrolysis (Elkhalifa et al., 2019), integrating FW management with wastewater treatment towards urban sustainability (Zan et al., 2022), and sustainable approaches for conversion and reutilization of FWs to valuable bio-products (Ng et al., 2020). In this vein, adopting suitable technical and economic strategies within a multi-disciplinary approach can support the development of a sustainable biorefinery of FW based on CE principles and bridge the gap between waste remediation and product recovery (Dahiya et al., 2018).

Waste-to-energy conversion technologies have appeared as one of the main background themes of FW research. In this regard, among different conversion technologies, including biological, thermal, and thermochemical, biological technologies, particularly anaerobic digestion, have played a significant role (Aghbashlo et al., 2019b; M. Du et al., 2021). Anaerobic digestion is a process in which a consortium of microorganisms breaks down biodegradable materials into biogas in the absence of oxygen (Dehhaghi et al., 2019; Pham et al., 2015). Interest in using anaerobic digestion to process source-segregated waste is increasing due to the opportunity of recovering additional value from waste such as nutrient-rich fertilizer products, in addition to biogas production (Aghbashlo et al., 2019a; Banks et al., 2011; Tabatabaei et al., 2020). Zhang et al. (2007), in a study on the characterization of FW as feedstock for anaerobic digestion, showed that FW, among other organic substrates, is a highly desirable feedstock for anaerobic digestion due to its high biodegradability and methane yield. In this regard, anaerobic co-digestion of FW and rendering industry streams for biogas production (Bedoić et al., 2020), FW anaerobic digestion for bio-energy production (Negri et al., 2020), identification of variables and factors that affect FW anaerobic digestion (Casallas-Ojeda et al., 2021), and FW anaerobic digestion impacts on biogas production and environment (Chew et al., 2021) are among recent research topics within this cluster.

Mismanagement of organic-based waste such as FW has posed significant economic and environmental challenges to global communities (Barati et al., 2017). In this vein, with the promotion of resource recovery, more attention should be paid to biorefinery technologies for producing energy from organic waste and biomass toward a zero-emission economy and production (Ren et al., 2018). According to Uçkun Kiran et al. (2014), FW to energy bioconversion to generate ethanol, methane, hydrogen, and biodiesel seems to be economically viable. To properly manage FW, anaerobic digestion is a promising conversion technology compared with traditional disposal methods, such as landfilling, composting, and incineration (Xu et al., 2018; Zhang et al., 2014). However, anaerobic digestion has not been widely used to convert energy from FW due to economic and technical challenges, such as economic viability and high cost, control process instability, foaming control, and low buffer capacity (Xu et al., 2018).

3.5.2. Cluster II: food waste supply chain management towards a circular economy: sustainability and environmental concerns

The research efforts in this cluster have been mainly focused on the managerial issues regarding implementing an effective FW management system in different sectors within the whole supply chain. In this vein, the sever challenges posed by FW to the environment, society, and economy regarding environmental pollution and resource depletion (Corrado and Sala, 2018) have been the main concern of governments, policymakers, and stakeholders involved in food supply chains.

The focal research in this area includes, but is not limited to, FW reduction and economic savings (Malefors et al., 2022), generation and prevention of FW (Strotmann et al., 2022), perspectives on social innovations for FW management (Al-Obadi et al., 2022), FW and its associate implications for food prices, production and resource use (Lopez Barrera and Hertel, 2021), FW management innovations in the foodservice industry (Martin-Rios et al., 2018), quantification of

FW along the food supply chain (Caldeira et al., 2019), implementing the CE paradigm (Ciccullo et al., 2021), and stakeholder partnership plans to fight FW (de Visser-Amundson, 2022). The main issues around environmental assessment in FW management practices have been outlined in environmental impacts and lifecycle assessment subject areas of research. For instance, environmental implications of recovering resources from FW (Scherhaufer et al., 2018; Slorach et al., 2019; Tonini et al., 2018), using different conversion technologies, such as anaerobic digestion (Slorach et al., 2019).

Achieving environmental sustainability and transitioning from a linear economy to a CE highly relies on effective waste management and how waste is treated as a potential future resource. FW management poses a significant challenge on the transition from a linear economy to a CE (Imbert, 2017). Growing awareness of the need for sustainability has encouraged literature to highlight the CE's potential to achieve sustainable development goals (Schroeder et al., 2019). Sharma et al. (2021) denoted that waste management influences all pillars of sustainability, then concluded that the CE brings long-term stability and provides economic, environmental, and social benefits. Over the last decade, the CE has attracted remarkable attention in the literature as a solution to tackle concerns about climate change, limited resources, unstable economic conditions, and exponential growth in generating waste (Khan and Paul, 2022).

The CE proposes a new paradigm for the sustainable food industry which considers waste minimization and value mining of wastes to gain economic benefit and mitigate environmental loss (Liu et al., 2021). Goyal (2020) summarized the role of the CE in the food sector as a key player in reducing waste and hunger and enhancing social equality. However, food systems encounter many challenges due to the interdependency with political, environmental, institutional, and technological factors. Moreover, food value chains face loss and waste during various stages of the supply chain, such as agriculture, harvest, storage, process, transportation, consumption, and post-consumption (Liu et al., 2021).

Nevertheless, the transition towards the CE is complex and deals with multiple challenges and barriers. Hence, the limitation of the linear economy and the benefit of implementing a CE has encouraged research communities to investigate the drivers and barriers toward the CE transition. Kirchherr et al. (2018) presented a detailed study on the CE barriers and distinguished four categories of barriers including cultural, regulatory, market, and technological. They also noted that there are interaction effects among different categories. The complexity of the CE, poor information about shelf-life wastes, and economic viability were outlined by Ali et al. (2021) as the main challenges towards implementing the CE in the food industry. Challenges regarding government support, incentives, and policies were highlighted by Kumar et al. (2021) as the main barriers in the circular agriculture supply chain. Weak legal enforcement, lack of investment in technologies, and behavioral barrier were proposed by Liu et al. (2021) as the main challenges to CE implementation in the agri-food sector. In two similar research conducted on the CE transition barriers in the food supply chain, while lack of technology, adequate FW estimation, effective supply chain design, and sufficient benefits were identified by Gedam et al. (2021), government policy and incentives, and enforcing environmental regulations were highlighted by Kumar, Raut, et al. (2022) as the main challenges in adopting the CE in food systems.

3.5.3. Cluster III: food waste behavior and consumption patterns

FW at the consumption stage is a direct consequence of consumer behavior (Di Talia et al., 2019), highlighting the significance of studying consumer behavior and its impacts on FW reduction worldwide. Notably, over 50% of the generated FW comes from household consumption (Amicarelli et al., 2022), representing a critical sustainability challenge that municipal governments need to address (Everitt et al., 2022) for both developed and developing countries (Brizi and Biraglia, 2021).

Changing the everyday food-related habits and behaviors of consumers is not easy (Boulet et al., 2021) and requires sufficient investment and effective initiatives. In this regard, the research communities have been investigating several factors and issues, such as identifying factors most affecting FW at the household level (Bravi et al., 2020), rural household FW characteristics, and driving factors (Li et al., 2021), food consumption patterns (Qian et al., 2022), and FW reduction practices as ethical work (Lehtokunnas et al., 2022).

More recently, as a response to the urgent call for action against the adverse effects of the COVID-19 pandemic, a massive amount of research has been conducted focusing on the effects of this pandemic on waste management systems, practices, and different waste streams. In this regard, households' FW has gained much attention, highlighting household FW behavior (Amicarelli and Bux, 2021; Vittuari et al., 2021), behavioral impacts on residential food provisioning, use, and waste (Babbitt et al., 2021), perceptions of people towards household waste management in the wake of the pandemic (Acharya et al., 2021), and waste production in households (Filho et al., 2021). On this basis, the pandemic has highly impacted the food consumption and purchasing habits of people (Pappalardo et al., 2020) leading to creating many challenges for food systems and businesses all around the world.

In this vein, the changes in food consumption behavior in the post-COVID era may be related to price increase concerns, FW awareness, and safety (Güney and Sangün, 2021). The research in this area has been mainly focused on stockpiling and FW during the COVID-19 pandemic (Brizi and Biraglia, 2021), FW reduction in times of crisis (Malefors et al., 2022), household FW behavior (Burlea-Schiopoiu et al., 2021; Qian et al., 2020; Rodgers et al., 2021), FW generation (Brizi and Biraglia, 2021; Everitt et al., 2022; Heikal Ismail et al., 2020; Jribi et al., 2020), food over-ordering (R. Sharma et al., 2021), and safety and food packaging (Kitz et al., 2021). Babbitt et al. (2021) showed that the increased food-purchasing behavior of households to gain self-sufficiency during the pandemic has increased waste through bulk purchasing and stockpiling. In another study, Filho et al. (2021) denoted that the COVID-19 lockdowns have resulted in higher consumption levels of take-away food and packaged products. Based on their research evidence, 45–48% of the participants reported consumption growth of fresh food, packed food, and food delivery due to longer stays at home. Nevertheless, despite the potential increase in FW generated during the pandemic, Vittuari et al. (2021) showed a considerable reduction in declared household FW due to uncertainty and increased availability of time at home by Italian households. Moreover, the research conducted by Ben Hassen et al. (2021) revealed that although the pandemic has increased the consumption levels of local food products due to food safety concerns, it has improved the awareness of people towards food, leading to FW reduction.

3.6. Conclusions

This chapter provided an inclusive image of the body of knowledge in FW research. To this end, a systematic bibliometric method, supported by (i) descriptive bibliographic analysis, (ii) keyword-based analysis, and (iii) bibliographic coupling clustering analysis, were used to uncover the main research backgrounds and emergent subject areas of research, building the FW literature. In this regard, performance indicators of the scientific production in FW research were presented, including publications' evolution over time, the most contributing journals, publishers, articles, countries, institutions, and funding agencies. Moreover, seminal research hotspots and emergent research areas within the FW sector were mapped and discussed. On this basis, the analysis revealed three main research themes, including (i) technological developments in FW treatment systems and biorefinery applications, (ii) FW supply chain management towards a CE: sustainability and environmental concerns, and (iii) FW behavior and consumption patterns.

The insights provided by the present systematic review are expected to help researchers and scholars to capture a general overview and landscape of the FW research conducted to date. Besides, it can be used as a guideline for policymakers and industrial practitioners to advance recent developments within the food supply chain management field.

Chapter 4: The Nexus of Food Waste and Sharing Economy: A Step Towards a Circular Economy?

4.1. Introduction

Many factors, such as the growth of internet applications and smartphones, globalization, and urbanization, the global economic crisis, shifts in general attitudes, and higher attention towards sustainability in consumption, have led to the advent of the sharing economy in recent years (Michelini et al., 2018; Mohlmann, 2015). The term sharing economy refers to the application of digital platforms to link consumers to services or goods via a mobile app or website (Cockayne, 2016). Apart from the variations in the specifications and characteristics of the sharing economy, a big ambiguity exists regarding the nature of the sharing economy. Regarding the theoretical framework that sustains the concept of the sharing economy and the factors that enable it, four core pillars for the sharing economy were introduced by the PWC network (PWC, 2015), namely (i) digital platforms that connect spare capacity and demand, (ii) transactions that offer access over ownership, (iii) more collaborative and trust-based forms of consumption, and (iv) branded experiences that drive emotional connection. Moreover, Muñoz and Cohen (2017) identified seven distinct dimensions of sharing economy models which are platforms for collaboration, under-utilized resources, peer-to-peer interactions, collaborative governance, mission-driven, alternative funding, and technology reliance. Schor (2014) assumed four wide categories for sharing economy activities, consisting of the recirculation of goods, increased utilization of durable assets, exchange of services, and sharing of productive assets. As can be seen, there is an open debate on how the sharing economy can be conceptualized.

The sharing economy business strategy recognizes the value of utilization while the consumers pay for using the product's functions, and not for its ownership (Belk, 2014; Sousa and Miguel, 2015). However, there are different types of sharing economy business models in literature. For instance, Laukkanen and Tura (2020) categorized sharing economy business models into 13 groups based on the focus they have on access economy (the idea of optimizing underused assets through access-based transactions rather than transferring ownership), community-based economy (non-contractual and non-monetized models), and platform economy (transactions are based on the transfer of ownership). Based on the kind of asset involved in the sharing (existing or new) and the kind of transaction enabled by the provider (temporary or permanent), Trabucchi et al. (2019) classified sharing economy business models into 4 groups, including seller aggregators (new, permanent), on-demand renters (new, temporary), lifecycle extenders (existing, permanent), and ephemeral matchmakers (existing, temporary).

Heinrichs (2013) considered product–service systems among the three features of the sharing economy. Moreover, servitization is considered an enabler for the sharing economy business models (Piscicelli et al., 2015) but it is also strongly linked with the CE paradigm (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Núñez-Cacho et al., 2018). This approach proposes a closed-loop vision of the material flows, instead of the linear "manufacture-use-dispose" view prevailing nowadays. Closing the loop through recycling or energy recovery is just a partial solution oriented to patching up the dominant model of the linear economy. Not only the sharing economy business models could support the transition towards a CE by promoting the extended products' lifetime, but also, they maximize utilization by occupying the idle capacity (Cho et al., 2019; Ranjbari et al., 2018). Projections show that the key sharing economy sectors including car-sharing, online staffing, music/video streaming, finance, and accommodation, have the potential to increase global revenues from roughly $15 billion today to around $335 billion by 2025 (PWC, 2015, 2014). Such exponential growth highlights the importance of the subject both in theory and practice.

Sharing economy implementation in the food sector through the emergence of food sharing digital platforms has the potential to significantly disrupt food commodity lifecycles within different stages from production to disposal (Falcone and Imbert, 2017; Harvey et al., 2020). Food sharing online platforms, an initiative to reduce FW generated through redistributing surplus food (Octavia et al., 2022), have provided potential opportunities to address FW at the consumer and retailer levels. Academic enthusiasm for digital platforms has gained momentum due to their significant ability to create value by minimizing transaction costs. On this basis, the emergence of digital platforms has sparked a robust and rapidly expanding field of scholarly inquiry, focusing on areas such as platform leadership and innovation, platform competition, and platform ecosystems (Gawer, 2021). Arguably, using digital platforms to share food surplus has gained attention as a promising strategy to fight FW and food insecurity at the same time (Makov et al., 2023). In this regard, digitally enabled FSPs can potentially tackle environmental concerns (Makov et al., 2020), and mitigate food insecurity and food supply disruption (Makov et al., 2023). Nevertheless, the effectiveness of using online FSPs and applications in FW reduction and contributing to the CE still lacks sufficient empirical research.

The application of the sharing economy in the food sector has received very limited attention compared to other sectors, such as mobility and accommodation. In this vein, a few research efforts have been conducted on FSPs and their applications from different perspectives, such as investigating the nexus of urban food sharing, information, and communications technology, and sustainability (Davies and Legg, 2018), people's underlying motivations to participate in food sharing (Schanes and Stagl, 2019), key factors for a successful FSP (Mazzucchelli et al., 2021), food insecurity (Nica-Avram et al., 2021), social and environmental implications (Makov et al., 2020), value creation in food supply chains (Choi et al., 2019), and potentials in FW reduction (Morone et al., 2018).

However, the food sharing realm is still in its infancy stage and faces challenges both in practice and research. Hence, the main aim of the current systematic review is to provide a comprehensive overview of FSPs and their associated implications.

The remainder of this chapter is structured as follows. Section 4.2 provides an overview of the sharing economy, including the main definitions, features, and conceptual framework characterizing the sharing economy business model. The adopted search protocol to conduct the systematic review, explaining the databases, search string design, and inclusion criteria is explained in section 4.3. Section 4.4 delivers the synthesis of the literature review to conceptualize the food sharing realm, outlining food sharing principles, food sharing business models, people's motivation for participation in food sharing activities, and food sharing implications and challenges for waste management in a CE. Finally, section 4.5 concludes the remarks.

4.2. Sharing economy framework: an overview

Through scrutinizing sixty-seven definitions presented in the literature for the sharing economy, Ranjbari et al. (2018) identified eleven main features characterizing sharing economy as stated in Figure 14. In order to clarify the similarities and differences between the identified features, these features are put into 7 groups, including (1) online platforms, referring to the intermediary role and convenience of participants, (2) temporary access, referring to a collaborative form of consumption to use idle capacity, (3) for-profit activities, (4) peer-to-peer connection, (5) sustainability concern, (6) trust and network-based activity, and (7) capability of operating at near-zero marginal cost.

Figure 14. Main features characterizing the sharing economy model adapted from Ranjbari et al. (2018).

Based on the analysis conducted by Ranjbari et al. (2018), although (i) using online platforms, (ii) temporary access without transferring ownership, (iii) more collaborative form of consumption, and (iv) using idle capacity are near to each other, they can be considered as standalone features. These features are crucial in shaping the sharing economy model and can be considered its main pillars. Moreover, the role of the sharing economy as an intermediary is noticed in some research (Grybaitė and Stankevičienė, 2016; Muñoz and Cohen, 2017) and it seems that this is a vital role for the sharing economy and should be considered in its main definition. The lower price provided by sharing economy activities and social aspects of the sharing economy, such as trust, are other elements that have been overlooked in the target literature.

Taking all sharing economy features into account, and the challenge for both the definition and framework of the sharing economy, Ranjbari et al. (2018) suggested considering the sharing economy as an economic system in which various companies provide platforms to facilitate the sharing activities. Hence, they defined sharing economy as an economic system, whose intermediary companies utilize online platforms to facilitate and lower the cost of the for-profit transactions of giving temporary access—without the transfer of ownership—to idle resources of consumers in the peer-to-peer networks based on trust built among its members, who may be individuals or businesses. In this definition, the sharing economy has been considered as an economic system in which an online platform connects the supply and demand sides, both of which are consumers, i.e., individuals or businesses that own a resource and use it and let others use its idle capacity. However, if a company owns a resource, uses it, and then shares its idle capacity with other companies or people, it is considered a sharing economy company. Moreover, considering the economic nature of the sharing economy, the for-profit activities mentioned in the definition do not always indicate monetary transactions, but sometimes the exchange of other tangible or intangible assets. Figure 15 presents the sharing economy framework.

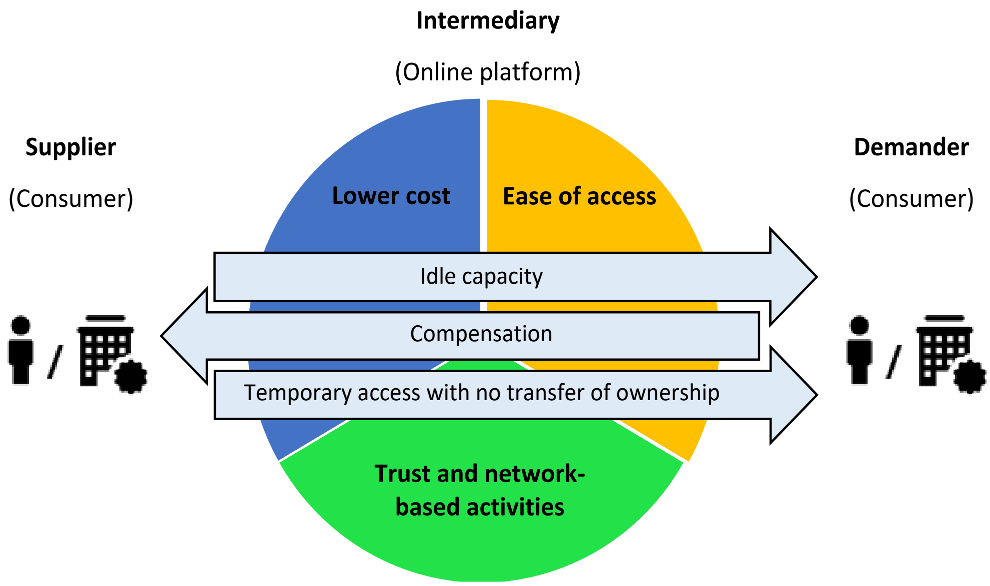


Figure 15. The proposed framework for sharing economy, adopted from Ranjbari et al. (2018).

4.3. Scope and the review methodology

This chapter aims to provide a comprehensive understanding of the food sharing concept and its main business models along with the main characteristics of digitally enabled FSPs and their challenges in the CE transition. In this regard, the following RQs are formulated to be addressed by conducting a systematic literature review:

RQ1. What are the main characteristics of digitally enabled FSPs?

RQ2. What are the main challenges of digitally enabled FSPs in a CE?

To achieve the main aim of the present chapter, a systematic literature review based on the PRISMA statement (Liberati et al., 2009), adapted from Fink (2019) and Traxler et al. (2020) was conducted on the food sharing concept. Adopting a well-structured search protocol, to ensure (i) a well-covered data source, (ii) an effectively formulated search string, and (ii) defining relevant inclusion and exclusion criteria seems crucial in conducting any systematic review. On this basis, the adopted search protocol to collect relevant data from the target literature, including database, search string design, and inclusion criteria is described in the following sub-sections.

4.3.1. Database

To ensure sufficient coverage of published papers and enrich the reliability of the gathered publications, Web of Science and Scopus were utilized as the research databases for record identification and collections in the current review. The Web of Science core collection covers all publications indexed in "Science Citation Index Expanded", "Social Sciences Citation Index", "Arts and Humanities Citation Index", "Conference Proceedings Citation Index- Science", "Conference Proceedings Citation Index- Social Science & Humanities", and "Emerging Sources Citation Index" (WoS, 2020). As a source-neutral abstract and citation database, Scopus provides a wide range of scholarly literature across many disciplines, including more than 75 million records, 24,600 active titles with more than 23,500 peer-reviewed journals, and 5,000 publishers (Elsevier, 2020).

4.3.2. Search string design

A structured search string was constructed aiming to maximize the sufficiency of the extracted documents related to the food sharing domain. In this vein, the two main concepts "food sharing" and "online platform" were considered as the core of attention for further investigation. To avoid neglecting critical and significant research within the food sharing arena as much as possible, these two concepts were divided and carefully scanned to outline the crucial keywords referring to the same concept. Consequently, having reviewed some recent studies focusing on food sharing (Mackenzie and Davies, 2019; Michelini et al., 2018), I ended up with two separate groups of keywords. On the one hand, the following keywords were considered as the main keywords in the literature referring to food sharing: "food sharing", "food-sharing", "sharing food", "food surplus", "food leftover", and "food rescue". On the other hand, "website", "Internet", "digital", "App", "industry 4.0", "platform", "online", "mobile", "smartphone", "ICT", "information and communications technology", "sharing economy", "IoT", and "internet of things" were selected to address the online platform. It is worthwhile mentioning that since the target literature is limited and the number of scientific productions in the digitally enabled FSPs is relatively low, the search string was not limited to any other related keywords, such as CE, circular supply chain, or food supply chain to provide an inclusive map of the food sharing domain.

Moreover, firstly, the identified keywords were connected by using the Boolean operators "AND" and "OR", and secondly, the character "*" was used with some of the identified keywords to capture all their derivations. As a result, the following search string for capturing the most relevant documents related to the FW background was constructed to search in the topic (i.e., title, abstract, and author keywords) of the documents:

(("food sharing" OR "food-sharing" OR "foodsharing" OR "sharing food" OR "food surplus" OR "food leftover" OR "food rescue")

AND

("website*" OR "Internet" OR "digiti*" OR "digital*" OR "app" OR "industry 4.0" OR "platform" OR "online" OR "mobile" OR "smartphone*" OR “ICT” OR "information and communications technology" OR "sharing economy" OR "smart" OR "IOT" OR "internet of things"))

4.3.3. Screening: inclusion and exclusion criteria

The initial run of the search string on the topic field in Web of Science and Scopus returned a total of 112, and 178 records, respectively. A two-stage delimitation process was considered to select the most relevant articles.

In the first screening stage, only scientific reviews and research articles published in peer-reviewed journals in the English language were considered. The other document types, such as conference proceedings, book chapters, notes, and letters, were excluded from the database to enrich the study's validity and quality. The rationale behind adopting this approach was to enrich the quality and validity of the collected data and accordingly analyses and obtained results (Ranjbari et al., 2021b). Besides, due to the aim of this research to provide a comprehensive review of the food sharing literature, no time-period restriction was considered. The continuous process of capturing data was stopped by adding the last update on December 31, 2022, to the dataset. In this stage 25, and 78 articles were excluded from the Web of Science and Scopus databases, respectively. Afterwards, 76 duplicated articles within both databases were eliminated, leaving 111 articles to be considered for the second screening stage.

In the second screening stage, the papers' content, which was filtered in the previous stage, was checked by first, reading the title, abstract, and conclusion, and second, reading the entire document to check the relevancy of the papers. In this regard, since the term "food sharing" also refers to some animal behavior in sharing food, during this screening stage, irrelevant articles were removed from the dataset. As a result, 83 articles were excluded, and finally, the sample was composed of 28 articles for scrutinizing in the current review. Table 14 summarizes the adopted search protocol and illustrates the overall process of the review.

Table 14. The details of the adopted search protocol to collect food sharing-related articles.

Search string	(("food sharing" OR "food-sharing" OR "foodsharing" OR "sharing food" OR "food surplus" OR "food leftover" OR "food rescue") AND ("website*" OR "Internet" OR "digiti*" OR "digital*" OR "app" OR "industry 4.0" OR "platform" OR "online" OR "mobile" OR "smartphone*" OR “ICT” OR "information and communications technology" OR "sharing economy" OR "smart" OR "IOT" OR "internet of things"))
Searched in	Topic: title, abstract, author keywords, and keywords plus
Database	Web of Science
Initial result	112 articles
Database	Scopus
Initial result	178
Duplicates	76
Inclusion criteria	(i) peer-reviewed journal articles, (ii) English documents, (iii) content relevance
The last update	December 31, 2022
Final sample	28 articles

4.4. Conceptualizing food sharing

Having systematically reviewed articles within the food sharing domain in the target literature, the concept of digitally enabled food sharing is conceptualized in this section. In this vein, food sharing definition and principles are described in section 4.4.1. Then, different business models to create value within the food supply chain through sharing food surplus are presented in section 4.4.2. People's motivations for participation in food sharing activities are discussed in section 4.4.3. Finally, section 4.4.4 synthesizes the implications and challenges of food sharing towards an effective waste management system in a CE.

4.4.1. Food sharing principles

There is no globally agreed definition for the concept of "food sharing" (Davies and Legg, 2018). Referring to the sharing economy definition, as an economic system utilizing online platforms to facilitate giving temporary access (i.e., without ownership transformation) to idle resources (Ranjbari et al., 2018), food sharing might be defined as selling food surplus through online platforms or gifting foods to food banks, as well as peer-to-peer marketplaces that facilitate the sharing activities (Davies and Legg, 2018).

Although food sharing activities were initially limited to household or kinship relationships, such as family or friends, the emergence of digital platforms has extended the domain of food sharing beyond this so that such activities can mobilize food sectors to share food surpluses with the needy (Octavia et al., 2022). Such platforms not only provide opportunities for peer-to-peer exchanges of food but also facilitate the transfer of unsold food between businesses (such as restaurants, supermarkets, bars, cafés, etc.) and consumers to reduce FW (Lucas et al., 2021). Such transfers within FSPs could be either non-monetary (e.g., the OLIO App) or monetary based on a discount pricing strategy (e.g., the TGTG App). As a result, FSPs enable local communities to address both FW concerns and food accessibility, as an effective action towards achieving sustainable development goals 2 (zero hunger) and 12 (responsible consumption and production) introduced by the United Nations (Lucas et al., 2021).

4.4.2. Food sharing business models

Alternative distribution channels in food supply chains using digital platforms have recently received attention as a solution to tackle the FW challenge worldwide. For instance, food banks, social supermarkets, and digitally enabled FSPs are some examples of such alternative distribution channels in the food sector.

Food banks refer to organizations that "typically acquire the foods from businesses and donors and store them with the necessary equipment, and then distribute them directly or indirectly to people in need through nonprofit and government agencies" (Ghahremani-Nahr et al., 2023). Food banks provide opportunities to avoid FW, help food insecurity, mitigate environmental pollution, and reduce greenhouse gas emissions (Penalver et al., 2022).

On the other side, social supermarkets, as a solution to reduce FW that mainly takes place in traditional food supply chains have been developed to ensure food access for socially endangered citizens (Knežević et al., 2021). Social supermarkets, typically nonprofit enterprises, provide food surplus for retailers for free and then retailers can sell the food at discount or subsidized prices to vulnerable sections of society (Michelini et al., 2018; Stettin et al., 2022). Such organizations can help food aid and create cultural, social, and political capital by reaching out to a more diverse population (Stettin et al., 2022).

Online platforms, functioning as electronic markets, facilitate the interaction among various platform participants by managing their communication, offering market overviews, ensuring transparency in pricing, aiding customers in their decision-making process, and disseminating pertinent information (Konietzko et al., 2019). Online platforms can contribute to implementing a CE by allowing organizations and individuals to share access to underused physical goods and thereby reduce their idle capacity to narrow, slow, and close resource loops in a CE (Konietzko et al., 2019). In other words, digitally enabled platforms empower circular business models that support the efficient use of resources and materials through extensive ecosystems of platform actors (Blackburn et al., 2023). Nonetheless, there remains a limited understanding of organizational structures and the internal mechanisms of such platforms (Blackburn et al., 2023).

Hence, the food sector has also benefited from this digital revolution by developing food surplus redistribution channels and online platforms in recent years. In this regard, digitally enabled FSPs have emerged to prevent FW and save the environment in a CE paradigm. However, since this phenomenon is still new, there is no common understanding of the business model of such platforms and how they work and create value within the food supply chain for involved stakeholders. Conducting a hierarchical cluster analysis on 52 food sharing cases, Michelini et al. (2018) categorized food sharing business models into three groups, including (i) the "sharing for money" business model, referring to a business-to-consumer for-profit business model to reduce FW and generate revenues simultaneously (ii) the "sharing for charity" business model, in which food is collected and distributed to non-profit organizations, and (iii) the "sharing for the community" business model, addressing peer-to-peer business models where consumers share food among each other. Arguable, digitalization in business models has brought some opportunities for existing social supermarkets and food banks to integrate online and traditional channels in distributing food by using web-based platforms and mobile applications (Michelini et al., 2018). Food sharing business models are described in the following sub-sections.

4.4.2.1. Food sharing for money business model

In this type of food sharing, generally, a provider (i.e., the owner of the online platform) links distributors (restaurants, supermarkets, bars, etc.) who have food surplus to potential consumers through using an online web-based or mobile application. In this way, distributors can advertise their food surplus, unsold food, or near-to-expire food products on the online platform and consumers can choose to pick up those food products at a discount price lower than the normal price. The platform provider, as an intermediary to link suppliers and consumers, takes a percentage of each transaction as a commission fee. Generally, such platforms work locally with geolocation systems for easier connections between distributors and consumers.

A well-known platform belonging to this business model of food sharing is Too Good To Go (TGTG). TGTG, as an initiative to ensure food is not wasted but consumed, allows consumers to buy and collect food surplus called "Magic Box" from bars, restaurants, grocery stores, and supermarkets at a super advantageous price (TGTG, 2022a). Hence, through the successful transactions in TGTG, on one side, consumers can buy food at lower prices and help FW reduction, on the other side, retailers can prevent FW, find new customers, and recoup lost costs. For instance, in Italy, TGTG has reached 6.9 million consumers and 23,611 businesses already registered in the TGTG platform, leading to a saving of 10 million magic boxes (food products) by 2022 (TGTG, 2022a).

4.4.2.2. Food sharing for charity business model

In contrast with food sharing for money, the providers of food sharing for charity platforms are mainly nonprofit organizations that enable collecting food products from businesses or consumers and distributing them to charities and nonprofit organizations. Thus, in this type of business model, the food delivery model is mainly business-to-business and consumer-to-business (Michelini et al., 2018). This food sharing model supports communities and businesses to connect with each other in new ways and effectively use the volunteers' potential in redistributing surplus food and tackling hunger in vulnerable populations (Davies et al., 2019).

An example of this type of food sharing is FoodCloud, established in 2013 by Iseult Ward and Aoibheann O'Brien, with a shared vision of no healthy food going to waste. FoodCloud as a social enterprise aims at distributing surplus food into opportunities to make the world a kinder place by linking businesses with charities and community groups that need it (FoodCloud, 2020). Activities of such platforms not only help food security and achieving sustainable development goal 2 (zero hunger), but also contribute to FW reduction and lower CO_2 emissions. For instance, FoodCloud redistributed 39 million meals in 2020 (i.e., approximately 16,380 tonnes of surplus food) in four countries, including Slovakia, the UK, Ireland, and the Czech Republic, which is equivalent to reducing approximately 52,416 tonnes of CO_2 emissions (FoodCloud, 2020).

4.4.2.3. Food sharing for the community business model

Food sharing for the community business model, also known as the per-to-peer food sharing business model, addresses both for-profit and non-for-profit organizations. In this type of food sharing business model, the delivery model is peer-to-peer and potential consumers can share their food surplus free of charge aiming at reducing FW at local levels (Michelini et al., 2018). Organizations involved in this type of food sharing do not necessarily monitor or manage volunteer and logistics issues, and instead, provide opportunities to create local communities and social networks to fight against FW.

OLIO is one of the most well-known food sharing for the community (i.e., peer-to-peer food sharing) platforms worldwide. OLIO connects neighbors with each other and also with local businesses to share their food surplus as well as other non-food household items. On this basis, OLIO as a peer-to-peer FSP empowers local communities with an effective and free solution to prevent FW and help businesses become zero FW. The impact of OLIO is considered notable so that it has approximately 6.3 million registered users from 62 countries who have shared around 65 million portions of food by 2022, equivalent to approximately 191 million car miles saved (OLIO, 2022).

4.4.2.4. The value proposition of food sharing business models

A business model describes how an organization using different elements and their relationship creates, delivers, and captures value. Thus, value creation is the core concept of any business model (Gasparin et al., 2022). Generally, food sharing initiatives have emerged to help societies reduce FW, mainly through FW prevention. However, any food sharing business model creates different values for different players within the food supply chain, including consumers, platform providers, and distributors. In fact, based on the business model of each food sharing initiative, the involved players benefit differently. Table 15 summarizes different value propositions of food sharing business models.

In this regard, according to Michelini et al. (2018), the food sharing for money business model, such as TGTG, provides (i) discounted food product for consumers; (ii) reduce FW, and increase awareness of FW for society; and (iii) reduce logistics or waste disposal costs, increase profit, and enhance reputation and image for platform providers. In contrast, the food sharing for charity business model, largely generate benefits for society through providing (i) free product for consumers; (ii) FW reduction, poverty alleviation, awareness increasing of FW, awareness increasing of poverty, directly addressing the society; and (iii) logistics costs reduction, and reputation and image enhancement for platform providers (Michelini et al., 2018).

Finally, as can be seen in Table 15, end consumers are the most benefited players within the food supply chain in the food sharing for the community business model. In this vein, while consumers benefit from discounted and as well as free products, they also can strengthen their connection with local communities through opportunities provided by peer-to-peer FSPs. Besides, FW reduction and awareness of FW in this business model help society similar to the food sharing for money business model.

Table 15. The value proposition of food sharing business models, adopted from Michelini et al. (2018).

	Benefit	**Sharing for money**	**Sharing for charity**	**Sharing for community**
Providers	• Reduce logistics/ waste disposal costs	✓	✓	
	• Improve profit	✓		
	• Enhance reputation and image	✓	✓	
Consumers	• Discounted products	✓		✓
	• Free products		✓	✓
	• Networking/ sense of community			✓
Society	• Reduce FW	✓	✓	✓
	• Increase awareness of food wastage	✓	✓	✓
	• Alleviation of poverty		✓	
	• Increase awareness of poverty		✓	

4.4.3. Motivations to participate in food sharing

While food loss mainly takes place at the production, postharvest, and processing phases of the food supply chain, FW mostly occurs at the end side of the chain, highlighting the need to consider habits, behaviors, and consumption patterns of consumers and retailers (Morone et al., 2018). In this vein, while in developing countries FW mainly is generated at the early stages of the food supply chain (i.e., food loss) due to technical and financial constraints, in developed countries FW largely arises at the later stages of the chain due to consumer behavior (Falcone and Imbert, 2017). Hence, incorporating FW prevention and reduction plans and incentives at the consumption level into national policy agendas seems crucial in effective waste management in transitioning towards a CE. Therefore, exploring people’s behavior and habits regarding food consumption to increase the adoption of FSPs seems crucial.

D’Ambrosi (2018) highlighted the lack of knowledge of consumers in the poor diffusion and adoption of FSPs. Knežević et al. (2021) in a survey on the general perception of consumers in Central Eastern European countries regarding social supermarkets, outlined that (i) consumers’ attitudes regarding social supermarkets are positive, (ii) less than 10% of the studied population think that existence of social supermarkets to share food is not necessary, and (iii) in some countries, such as Poland, Lithuania, and Croatia respondents believe that social supermarkets should be more focused on FW reduction rather than poverty alleviation. Wang et al. (2020) showed that "voluntary food sharing with choice resulted in a more positive evaluation of the sharer’s willingness-to-help for a third party than a non-sharing parallel eater. This effect was not significant on the participants’ ratings of other people’s likelihood of donation to charity, and this discrepancy between two measures may be attributed to the difference between helping and donation". Schanes and Stagl (2019) denoted that members of a FSP are mainly motivated by identity and sense of community, emotions, and morality, social influence, reward, and instrumentality. Their findings showed that individuals involved in FSPs have different views on what such platforms should and can achieve (i.e., on the one hand, some players want to upscale the food sharing initiative and distribute more and more food; on the other hand, others prefer more food surplus prevention). Lin et al. (2022) in an analysis of the motivation for food sharing by peer-to-peer dining revealed (i) three factors, including gaining authentic experience, seeking variety, and enhancing social circle as push dimensions; and (ii) six factors, including atmosphere, value, food item, relationship with the host, type of food, and service quality as pull factors.

4.4.4. Food sharing implications and challenges for waste management in a circular economy

Given the novelty of the urban FSPs, the contribution of the food sharing initiatives to the CE transition and a sustainable food supply chain is still blurred (Sarti et al., 2017). Michelini et al. (2020) proposed an impact assessment framework for FSPs, considering four dimensions, including economic, environmental, societal, and political. According to their framework, economic indicators to assess the economic impact of such FSPs are increased food recovery, improved corporate, image improved procurement, cost reduction for local administration, cost reduction for providers, number of new microenterprises and local farms involved in the platform and items shared/sold, and startup and growth rates of microenterprises. On the other side, environmental indicators include the reduction of businesses' saleable and unsaleable FW, reduction of FW at the consumer level, CO_2 emissions saved, and municipal waste generated. In this vein, event attendance, visibility, increased networking, increased volunteering, improved access to affordable food, the amount saved, and healthy food shared, are among societal indicators. And finally, meetings with institutions and policymakers, partnership or joint initiatives with public institutions, changes in policy and legislation, level of relevant parliamentary activities, and incentives to waste reduction perform as political indicators in measuring the impact of FSPs. Moreover, Mackenzie and Davies (2019) developed an indicator framework to assess the sustainability impact of food sharing initiatives in urban food systems, containing 34 indicators corresponding to the social, economic, environmental, and governance pillars of sustainability.

Apart from the question of to what extend food sharing initiatives have achieved their objectives, how to assess any sustainability achievement is quite challenging due to the nature of such activities and the lack of sufficient information about the users' profiles, perspectives, and behavior (Hennig, 2019). The sustainability of the food sector has benefited from emerging FSPs to some extent since they have addressed social inequality and food poverty, engagement of policymakers and local authorities, and environmental outcomes of waste reduction (Michelini et al., 2020). Choi et al. (2019) denoted that in a decentralized food supply chain setting, food leftover sharing could be beneficial to the supply chain stakeholders, including distributors, consumers, and the environment.

In contrast, many argue that although FSPs have provided an opportunity to prevent FW through distributing food surplus, the use of such applications can result in rebound effects, leading to emerging different lines of businesses for retailers to sell more food products. In this regard, as highlighted by Yu et al. (2022) and Meshulam et al. (2022), further research is required to investigate the potential rebound effects of FSPs to see whether the food sold on the platform is effectively a surplus or a planned production. Moreover, using online FSPs does not necessarily result in FW reduction since it depends on several factors, such as economic awareness, collaborative behaviors, environmentally friendly behavior, and domestic skills (Morone et al., 2018) which should be considered with a systems thinking approach.

Digitalization in FSPs has provided many opportunities, such as easy online or smartphone scheduling of work, facilitating food surplus collections, increased transparency and speed, waste reduction, and lower transportation and warehousing costs (Klumpp and Ruiner, 2018). However, since a portion of the population (e.g., elderly people) are not used to new technologies, web-based platforms, and mobile applications for their everyday activities, they might be excluded (Klumpp and

Ruiner, 2018). This might lead to losing the potential of some volunteer engagements in contributing to effective food sharing among people who need it.

Moreover, although digitalization plays multiple roles in FSPs, such as linking potential distributors and consumers to share food surplus and data monitoring on FW, it is not sufficient for food recovery (de Almeida Oroski and da Silva, 2022). On the other side, adequate planning and optimization models are required to properly design FSPs so that they effectively (i) address food donors and food consumers through properly prioritized food donation events, (ii) link food donors with potential volunteers in a real time (Sanyal et al., 2021). For instance, finding the right locations (i.e., locational planning) for establishing social supermarkets, as one of the non-for-profit organizations involved in food sharing activities, to provide better access to offer food to needy people seems crucial (Lienbacher et al., 2021).

Many outcomes of food sharing initiatives are not directly economically motivated but support community-building, social connection, and environmentally friendly activities. However, since food and accordingly food supply chains are different from other products and supply chains due to well-being and health issues, social movements in this area are challenging and need effective management and accurate settings. Engagement between food sharing and policy and planning takes place mainly at the junctures of food health and safety (Edwards and Davies, 2018). Arguably, food health and safety are the most important issues that consumers consider when they share their food, especially in the case of peer-to-peer or sharing for the community model. This is in line with the research conducted by Diekmann and Germelmann (2021), highlighting the significance of health issues in participating in food sharing activities, especially in the case of food leftover consumption provided by some FSPs.

Several scholars argue that food is a particular type of product due to several facts, such as (i) food is a life necessity, (ii) food is a human right, (iii) food is highly sensitive in terms of health, safety, durability, and quality, and (iv) food has a specific social and cultural value (Zurek, 2016). Consequently, incorporating sharing economy in the FW system through digitally enabled platforms faces several barriers, including (i) trust among stakeholders, (ii) behavior and consumption patterns of different players within the food supply chain, and (iii) satisfying multiple needs for heterogeneous actors (de Almeida Oroski and da Silva, 2022). Considering such specific characteristics of food, how the sharing economy has embraced the food sector by enabling online FSPs has posed several risks to individual health, public health, and safety, highlighting the need for traceability, and official alert systems to protect consumers (Zurek, 2016). In this regard, while food is shared in the new era of digital-mediated FSPs, its associated risk responsibility is commonly individualized, calling for proper amendments within the existing governing arrangements (Davies and Evans, 2019).

4.5. Conclusion

Having conducted a systematic literature review in this chapter, comprehensive state-of-the-art of FSPs and applications was presented. In this regard, sharing economy and its main features and concepts were mapped to provide a conceptual framework characterizing the sharing economy principles. Then, the contribution of the sharing economy to the food sector in the form of sharing food surplus through using web-based platforms and mobile applications was scrutinized. As a result, food sharing fundamentals, including (i) different business models and value creation mechanisms, (ii) motivations to adopt such platforms, and (iii) implications for FW, sustainability, and CE transitions along with challenges and research gaps ahead were discussed.

The findings showed that food sharing business models can be categorized into three groups, including food sharing for money, food sharing for charity, and peer-to-peer or food sharing for the community (Michelini et al., 2018). Incorporating FW prevention and reduction plans and incentives at the consumption level into national policy agendas seems crucial in effective waste management in transitioning towards a CE. In this regard, FSPs face several challenges, such as the impact assessment of food sharing on sustainability and CE, the rebound effects of such platforms for production and consumption, and the adoption of FSPs in urban communities. However, given the novelty of the urban FSPs, the contribution of the food sharing initiatives to the CE transition and a sustainable food supply chain is still blurred (Sarti et al., 2017), calling for further investigations. The provided insights can support food supply chain stakeholders in enabling sharing economy in the food sector to (i) reduce FW through FW prevention, (ii) tackle environmental concerns related to the huge amount of FW, and (iii) create strong social communities and use volunteer potential to help food security and poverty alleviation towards achieving sustainable development goals 2 (zero hunger) and 12 (responsible consumption and production).

Section III

Case Study and Methodology

Section overview

This section presents two chapters, including the case study and methodology.

- In the first chapter (Chapter 5), the "Too Good To Go" FSP in Italy, as the case study considered in the current thesis, is introduced in detail.

- In the second chapter (Chapter 6), System Dynamics as the method adopted to develop the simulation model for FSPs is described step by step.

Chapter 5: Case Study: "Too Good To Go" Food Sharing Platform in Italy

5.1. Too Good To Go food sharing platform

The Too Good To Go (TGTG) platform is one of the most well-known examples of food sharing for money business models worldwide. TGTG was founded in 2016 in Copenhagen and is now active in 17 countries, saving more than 250,000 meals every day (TGTG, 2022b). This platform was initiated aiming at reducing FW through increasing FW awareness and FW prevention by making food surpluses available to consumers. The number of users and the food they have saved through using the TGTG platform have been dramatically increasing to date, as illustrated in Figure 16, from 479,424 meals saved in 2016 to 52,554,009 in 2021 (TGTG, 2022c). In total, TGTG has led to saving over 52 million meals by the end of 2021 (i.e., 2016-2021) which is enough to feed the entire population of South Korea (TGTG, 2022c). Besides, the TGTG application ranked 10th among the most downloaded applications in the food and beverage industry in the world, highlighting the significant attention gained by this FSP (TGTG, 2022c).

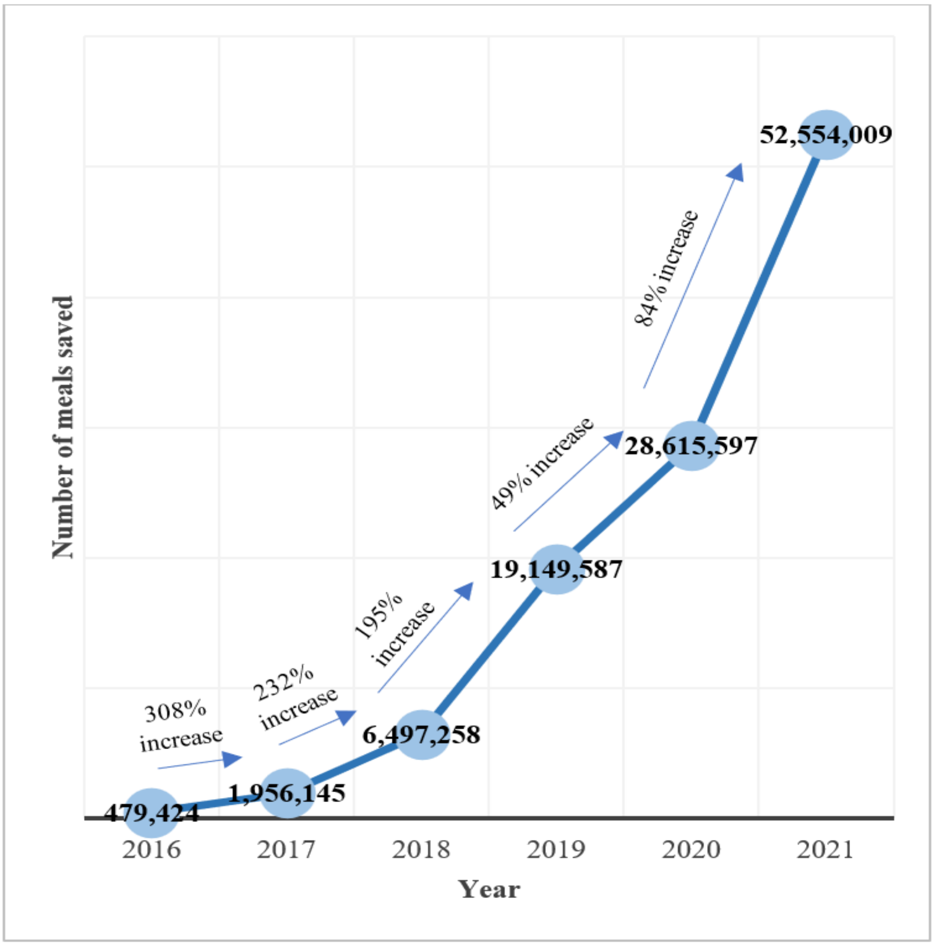


Figure 16. The number of meals saved per year through the TGTG platform in the world.

TGTG, through its online platform, offers potential consumers the possibility of ordering food product surpluses from potential points of sale (i.e., supermarkets, restaurants, groceries, bakeries, hotels, etc.) at a discount price. In other words, TGTG organizes the sale of the food surplus using the online platform on behalf of the retailers (i.e., acts exclusively as a paying agent) without any contractual relationship between TGTG and consumers (buyers) related to their sale (TGTG, 2020). Hence, TGTG does not make, sell, or purchase any food product, and instead, mediates consumers and distributors to prevent food surplus or unsold food products from going to waste. As a result, through the successful transactions in

TGTG, on one side, consumers can buy food at lower prices and help FW reduction, on the other side, retailers can prevent FW, find new customers, and recoup lost costs.

According to the terms and conditions of TGTG (TGTG, 2020), any potential user using the TGTG app for any reservation should (i) be a consumer buying food products for personal consumption, not with business purposes, (ii) have the legal capacity to enter into binding agreements, and (iii) be at least 18 years old with a valid debit, credit or other means of payment for online transactions. Since the main goal of TGTG is to avoid FW, if the food sellers do not have a food surplus, they may cancel the order up to two hours before the start of the agreed time for the withdrawal. In this case, TGTG will notify the consumer about the order cancellation and the consumer will be fully reimbursed (TGTG, 2020).

5.2. TGTG in Italy

TGTG began its activities in Italy in March 2019 and by the end of 2022, 6.9 million Italians were already using TGTG to order food products from 23,611 points of sale registered in TGTG, resulting in saving 10 million magic boxes (TGTG, 2022a). Given the increasing number of users, the TGTG initiative as a successful food sharing app has a large presence in Italy (Fragapane and Mortara, 2022). In this regard, TGTG has managed to reach over 45,000 partners, such as Carrefour, EATALY, naturasi, coop Centro Italia, GROM, and Venchi 1878.

On the TGTG app, the consumers can find the list of active points of sale, mainly based on a geographical criterion for localization services, and make an order. The prices of food items in TGTG often range from 1.99 to 4.99 euros, which are approximately one-third of their original values claimed by the points of sale. Signing up in TGTG is free for any individual or business. However, for businesses, an annual fee of 39 euro (only if they start selling the food product) in addition to a small commission for any order (depending on the price of products) is charged by

TGTG. Users have the possibility to filter the results based on the availability of the food, the pick-up time, and the type of food contained in the "Magic Box", also known as the "Surprise Bag". The interface of the TGTG mobile app is shown in Figure 17.

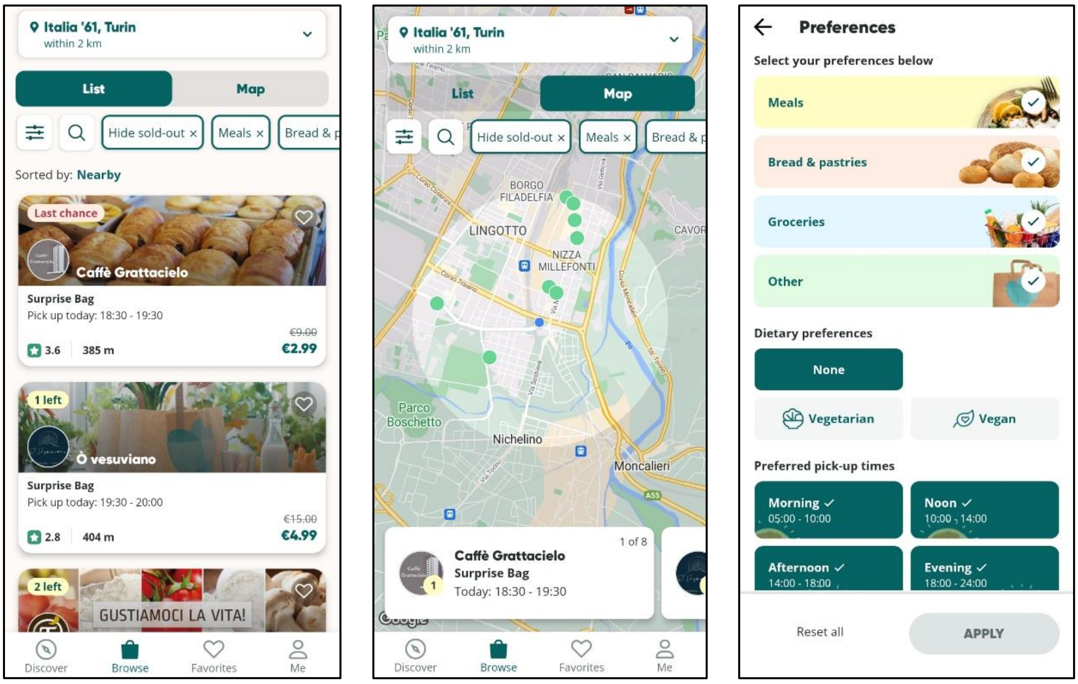


Figure 17. The customer interface of the TGTG mobile app.

5.2.1. The "pact against food waste" initiative

TGTG activities are not limited to points of sale, such as supermarkets, bars, restaurants, etc. They also collaborate with different partners, including companies, schools, and institutions to better influence the food system and public perception of FW. Hence, TGTG has based its activities on four main pillars, including people, companies, schools, and politics (Fragapane and Mortara, 2022). For the first pillar, TGTG aims at inspiring consumers to help with FW prevention by providing information and raising their awareness of the FW phenomenon. To this end, TGTG uses its website and blog, and social media channels, including Instagram, Facebook, and Twitter. Regarding businesses, as the second pillar, TGTG tries to involve various food-related businesses, such as bakeries, restaurants, supermarkets, and hotels in FW reduction practices within different stages from food production to retail and consumption. TGTG has so far involved 500 schools in Italy, as the third pillar, by organizing different classes and seminars targeting FW information and awareness. And finally, TGTG aims to help governments and authorities involved within the whole food supply chain establish effective policies in the battle against FW.

As an effective action in this regard, TGTG along with some partners has launched an initiative named the "pact against food waste" in 2021 to make an alliance between consumer associations, businesses, and companies to fight FW more effectively. This pact outline several solutions, including (i) providing a "conscious label" for food products to help the consumer better understand the difference between the "best before" date and "use by" date on food products, (ii) increasing the awareness and knowledge of businesses and companies regarding FW implications and FW reduction, (iii) enhancing the knowledge of consumers to become more familiar with FW prevention and food consumption patterns, (iv) supporting large-scale supermarkets against FW, and (v) supporting factories to reduce FW of products left in the warehouse more effectively (TGTG, 2021).

In Italy, the difference between the "best before" date and the "use by" date on food products is very subtle and often creates confusion. According to a survey, 63% of Italians misunderstand the difference between the labels "best before" date and "Expiration" or "use by" date on food products (TGTG, 2022d). Hence, this might lead to a large portion of FW in Italy. For instance, incorrect interpretation of the wording on the labels of food products has contributed to 10% of FW in European countries (TGTG, 2022d).

TGTG along with some partners has launched an initiative named the "conscious label campaign" to educate, inspire, and provide information for food consumers to better understand this difference and thus reduce FW (TGTG, 2022d). While a food product that has passed its expiry date (i.e., use by) can pose a risk to the consumer's health, the date "best before" shows the estimation of the best quality period for the food product. In this regard, TGTG invites people to look, smell, and taste the food products that have passed their "best before" date to avoid throwing consumable food away, by launching 10 million products that present the specifications of the "best before" date. For instance, flour and cereals, dried pasta, rice, and couscous are often good for 1-2 months after their "best before" dates. Other examples could be spices and aromatic herbs, sauces such as mayonnaise, ketchup, and mustard, and fruit juices which often can last for 6 months after their "best before" dates. Surprisingly, some food products, such as ground coffee, tea, bottled water, and tuna in oil can even last for one year after their "best before" dates. However, the diffusion of the "conscious label" campaign in Italy remains limited, and its accurate impact on the amount of FW prevention is underexplored (Annunziata et al., 2022).

5.2.2. TGTG in academic databases

It seems that TGTG as an anti-waste platform has a win-win business model for players, since (i) consumers can buy food products at a discount price (one-third of the original value), (ii) retailers can sell their unsold food products to cover their cost and generate some lines of revenue, (iii) the TGTG platform through linking buyers (consumers) to sellers (retailers) gain money, and (iv) the FW prevented help the environment, FW management systems, and resource efficiency towards an effective CE transition. However, due to the novelty of the topic, the academic research in this area focusing on food sharing for money platforms, in particular, TGTG, is still very limited. For instance, searching TGTG in both the Web of

Science and Scopus databases returned only 4 unique articles, as presented in detail in Table 16.

Table 16. All research conducted on TGTG available in the Web of Science and Scopus databases until January 6, 2023.

References	(Mathisen and Johansen, 2022)	(Fragapane and Mortara, 2022)	(Vo-Thanh et al., 2021)	(Zaman et al., 2021)
Research focus and objective(s)	Evaluating the effect of using mobile applications designed for FW reduction on FW, financial expense, and personal healthy eating	Assessing the impact of TGTG on the consumers' awareness in the fight against FW.	Examining how TGTG can be a catalyst for sustainable social business.	Studying how TGTG is perceived as a strategic food distribution channel in times of crisis such as a pandemic.
Geographical scope	Norway	Italy	France	France
Method	Survey/pilot intervention	Mixed: (i) survey (interview), (ii) content analysis (Facebook groups analysis)	Survey (semi-structured interview)	Survey (interview)
Findings	(i) FW awareness increased after the TGTG app trial. (ii) TGTG seems to be more concerned about the distributors' interests than the consumers' needs. (iii) TGTG did not result in any measurable effects within a two-month period trial regarding FW,	TGTG has a large presence on the national territory in different Italian regions. TGTG is a successful food sharing app in Italy in terms of the number of users. Consumers seem to put more emphasis on the	Social, emotional, and functional values are the success factors of TGTG in accomplishing its social mission.	Most consumers buy additional items while collecting their food products. TGTG has provided a cross-selling opportunity for retailers.

	improved healthy eating, and personal costs.	quality of food and saving money than on FW prevention.

Mathisen and Johansen (2022) conducted a pilot intervention study on a group of students to evaluate the effect of using mobile applications designed for FW reduction, considering TGTG as a case. In their research, having observed the changes after a two-month trial using TGTG, they concluded that although consumers' FW awareness increased, TGTG did not result in any measurable effects regarding FW, improved healthy eating, and personal costs. This might be acknowledged by the fact that changing the everyday food-related habits and behaviors of consumers is not easy (Boulet et al., 2021) and requires sufficient investment and effective initiatives in a long run. According to the research conducted by Fragapane and Mortara (2022), TGTG users in Italy seem to put more emphasis on the quality of food and saving money than on FW prevention. Vo-Thanh et al. (2021) through conducting a semi-structured interview with consumers and retailers involved in TGTG in France, highlighted that the main success factors of TGTG in accomplishing its social mission are social, emotional, and functional values.

Investigating TGTG as a strategic food distribution channel in times of crisis such as the COVID-19 pandemic, Zaman et al. (2021) denoted that many consumers buy additional products while they are picking up their food products ordered in TGTG, leading to a cross-selling opportunity for retailers to increase their revenue. Moreover, while 76% of consumers who discover a shop thanks to TGTG become customers, 58% of TGTG become regular customers (TGTG, 2022e). In contrast, although TGTG has provided an opportunity to prevent FW through distributing food surplus, it can result in rebound effects, leading to emerging different lines of businesses for retailers to sell more food products. In this regard, as highlighted by Yu et al. (2022) and Meshulam et al. (2022), further research is required to investigate the potential rebound effects of FSPs to see whether the food sold on the platform is effectively a surplus or a planned production to generate revenue.

On the one hand, although the number of TGTG users using food sharing services is increasing, the level of diffusion of using this platform among Italians in the future is not clear. On the other hand, the contribution of TGTG to FW prevention is not clear and faces some challenges. Therefore, the potential of FSPs in preventing FW and supporting the circular food system over time is still lacking. Hence, this thesis aims at simulating the diffusion of TGTG in Italy over time and predicting its impact on FW prevention and the CE transition by developing a System Dynamics simulation model.

Chapter 6: Methodology: System Dynamics Modeling

6.1. Introduction to System Dynamics modeling

Without simulation, even the best-developed conceptual models can only be tested and improved through learning feedback in the real world, which is very slow, inadequate, and costly. Therefore, simulation modeling is considered as the only reliable method to effectively test potential hypotheses and examine the likely effects of policies and decisions (Sterman, 2000).

System Dynamics, as a branch of systems theory, was introduced by Jay W. Forrester in the 1950s to simulate the long-term effects of policies and management actions that cannot be captured simply due to the complexity of interacting players in a system (Forrester, 1961). System Dynamics is a computer-aided simulation method where a model of causalities in a real-world complex system is developed, parameterized, and validated using real-world information (Dianati et al., 2021) to policy analysis and design (Kopainsky et al., 2018). In other words, System Dynamics is based on understanding how different variables in a complex system interact with each other in a particular case over time. This system analysis approach is able to deal with large-scale, linear, and non-linear interactions, dynamics, and complex systems (Sukholthaman and Sharp, 2016).

System Dynamics draws upon both quantitative and qualitative methods to involve stakeholders in defining mental models and support scholars to adopt non-linear thinking to understand and map the feedback processes of problem dynamics

(Galli et al., 2019; Turner et al., 2016). System Dynamics is employed to dynamic problems within dynamic systems (e.g., food supply chains) characterized by mutual and interdependence interactions, information feedbacks, and circular causalities (Kopainsky et al., 2018). Compared to other simulation methods, System Dynamics offers a decision framework that extends over the long term and possesses the ability to handle time delays and internal feedback loops that impact the behavior of the entire system (Sterman, 2000).

Waste management policymakers need standard tools in dealing with multiple sources of complexity in the transition towards a CE. In this regard, the System Dynamics simulation tool facilitates coping with such increased complexity by applying closed-loop thinking and identifying causal structures within the system (Guzzo et al., 2022). Due to the ability of System Dynamics in modeling complexity and generating simulated scenarios depending on the variations of variables, it has been widely used by scholars in different disciplines and domains. In this vein, System Dynamics has been used in different lines of waste management practices to simulate dynamics and interrelationships in FW management (Lee et al., 2019), biodegradable waste management (Babalola, 2019), municipal solid waste management and financial analysis (Pinha and Sagawa, 2020; Rafew and Rafizul, 2021), and FW reduction and food poverty alleviation (Galli et al., 2019).

6.2. System dynamics modeling steps

Modeling is a creative endeavor where modelers have the flexibility to adopt various approaches and styles. However, following a disciplined process significantly helps modelers develop more reliable models in a reasonable manner. In this regard, Sterman (2000) proposed a five-step process to develop a System Dynamics model, including(Sterman, 2000): (1) problem articulation and boundary selection to determine the modeling purpose, (2) dynamic hypothesis formulation to provide a conceptual framework of the complex system, (3) simulation model formulation to convert the conceptual model to a simulation model with equations, (4) model testing to calibrate the model behavior, and (5) policy design and evaluation for improvement to test different scenarios and observe the effects of changes.

In this vein, while steps 1 and 2 are often associated with 'soft systems' since they need conceptual modeling of the interactions among variables, steps 3 and 4 are associated with the 'hard systems' domain since they require quantification (Turner et al., 2016). Having divided modeling into different steps, it should be noted that modeling is not a linear sequence of these steps but a feedback process since System Dynamics models are continuous and iterative (Sterman, 2000). The iteration process can take place from any of those five steps to any other step as shown in Figure 18. Figure 19 illustrates the System Dynamics modeling steps corresponding to different chapters of the thesis.

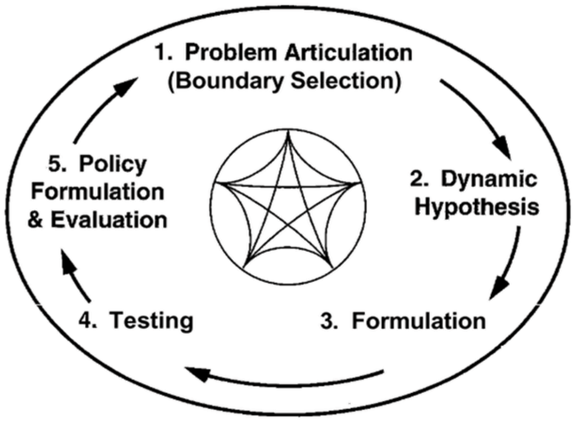


Figure 18. The iterative process of System Dynamics modeling.

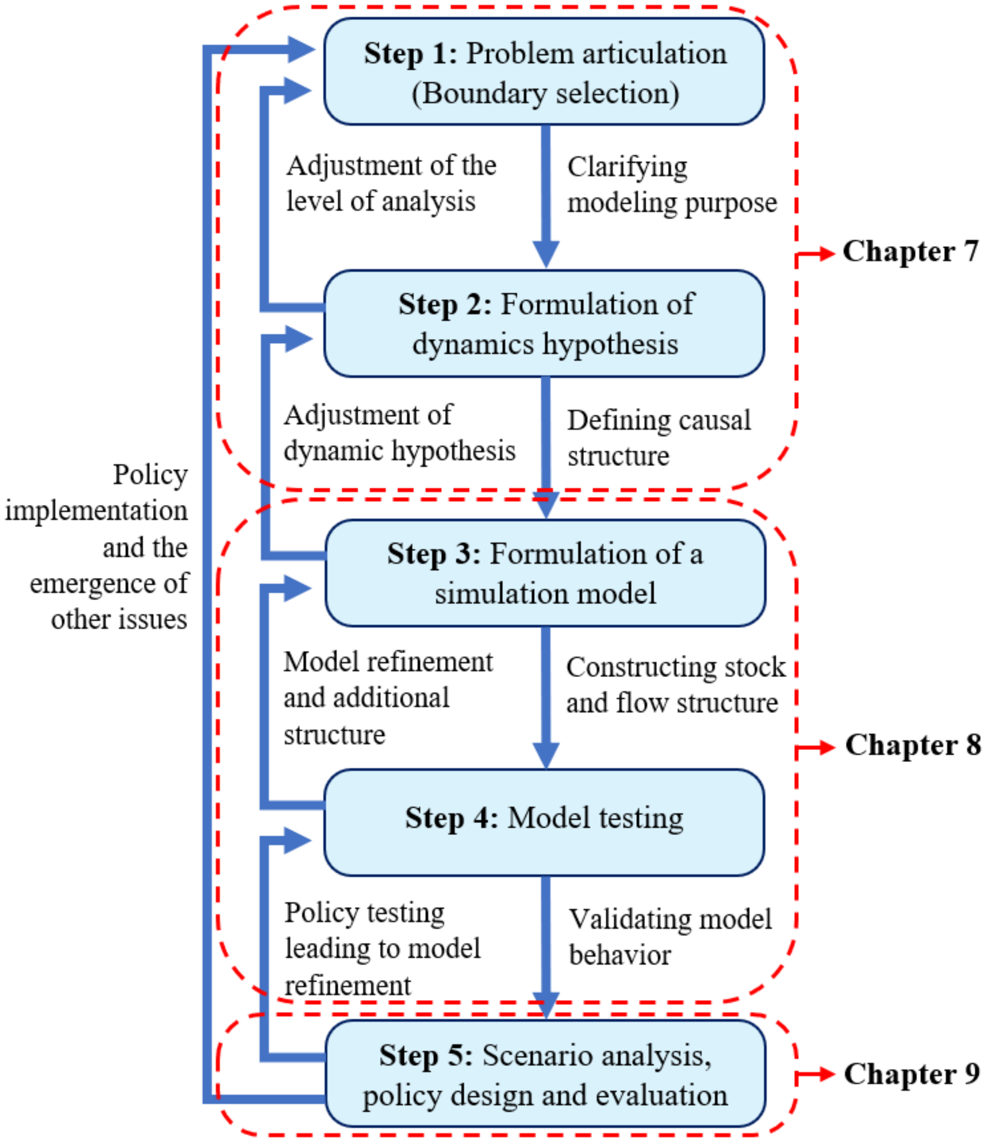


Figure 19. System Dynamics modeling steps adapted from Guzzo et al. (2022) and Sterman (2000).

It is worthwhile mentioning that these steps are described in the following sub-sections in general. Then, based on the model development process in the current thesis, they are described in detail in the next chapters. On this basis, as shown in Figure 19, the first two steps are presented in detail in Chapter 7. Steps 3 and 4 are explained in Chapter 8. And finally, the last step is delivered in Chapter 9.

6.2.1. Step 1: problem articulation

Problem articulation is the most critical step in System Dynamics modeling since it addresses the main purpose of the model. In fact, the problem should be clearly formulated to directly meet the needs of stakeholders who face difficulty. In this step, having determined the main purpose or problem, the following two elements should be defined: variables, and time horizon.

There are three different types of variables in System Dynamics modeling, including endogenous variables, exogenous variables, and excluded ones. While endogenous variables emerge within the system boundary (i.e., inside the scope of the model), the exogenous ones are derived from outside of the system (Binti Hasan, 2019). Obviously, excluded variables are variables that are not in the scope of the model. In this vein, if an exogenous variable enters the model, the model can generate the behavior of endogenous variables over time by capturing the interactions among variables. In formulating the problem, the number of exogenous variables should be small since the focus in System Dynamics modeling is on the endogenous variables rather than exogenous ones. Therefore, it is of utmost importance to clearly determine the system boundary and endogenous and exogenous variables.

Moreover, the time horizon for modeling should be defined in this step. The choice of time horizon significantly affects the problem perception during the modeling process. According to Sterman (2000), "the time horizon should extend far enough back in history to show how the problem emerged and describe its symptoms. It should extend far enough into the future to capture the delayed and indirect effects of potential policies". Besides, dynamic problem definition should also be done in this stage, to capture the historical and future behavior of the key concepts and variables (Shams Esfandabadi, 2022) to support a better understanding of the problem (Suryani et al., 2010).

6.2.2. Step 2: dynamic hypothesis formulation

After formulating the problem with a proper time horizon, System Dynamics modelers should develop the dynamic hypothesis to justify the problematic behavior. A dynamic hypothesis is (i) a working theory of how the problem arises and guides modeling efforts by focusing the modelers on certain structures, (ii) dynamic since it describes the dynamics characterizing the problem based on its main feedback, and stock and flow structures, and (iii) a hypothesis since it is always provisional and subject to revisions during the process of modeling (Sterman, 2000).

As a crucial element in this step, causal links among different variables based on initial hypotheses should be mapped using tools, such as causal loop diagrams and stock and flow maps, to provide an insight into the whole system. Causal loop diagrams explicitly present the structural and agent system elements that may endogenously generate the dynamics in the behavior of the system (Shams Esfandabadi et al., 2022). In this regard, the feedback concept is the core of System Dynamics modeling, and a feedback loop exists when the results of an action within a system influence its point of origin and potentially affect future actions (Kopainsky et al., 2018). On this basis, there are two different feedback loops in System Dynamics modeling, including reinforcing (positive) and balancing (negative) feedback loops in accordance with the polarity.

Reinforcing loop refers to dynamics when the increase of variable X leads to an increase in variable Y and then the increase of variable Y leads to an increase in variable X again. In contrast, in a balancing loop, increasing variable Z results in increasing variable Y but increasing variable Y leads to a decrease in variable Z. An example of a causal loop diagram containing positive and negative loops in this step is illustrated in Figure 20. Positive (+) and negative (-) signs located on the arrows show their polarity. The indicated polarities help identify positive (reinforcing) and negative (balancing) feedback loops within the presented structure. In other words, while positive feedbacks in a system show a self-reinforcing process, negative feedbacks indicate a self-correcting one (Sterman, 2000). In fact, the most complex behavior usually arises from the feedbacks (interactions) among variables of a system rather than the complexity of the variables themselves (Sterman, 2000). Hence, the main art of System Dynamics modeling is unfolding and representing such interactions.

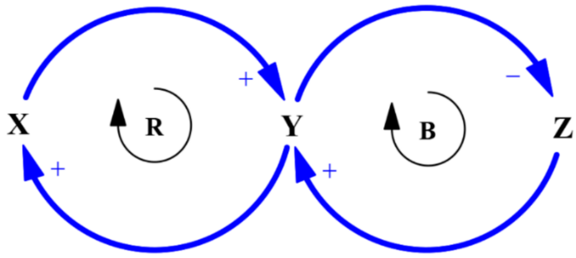


Figure 20. Reinforcing (R) and balancing (B) loops in a generic structure of causal loop diagrams.

6.2.3. Step 3: simulation model formulation

In this step, the conceptual structure built in the previous step is converted into a stock and flow diagram using mathematical equations determining the interconnections among variables (Shams Esfandabadi, 2022). This step allows the developed model to be evaluated quantitatively (Binti Hasan, 2019). This step allows the modeler to quantitatively evaluate the built model (Binti Hasan, 2019) and identify vague concepts and resolve contradictions that went unnoticed or undiscussed during previous stages (Sterman, 2000). The real test of what the modeler has built takes place in this stage.

A stock and flow diagram is (i) capable of further distinguishing variables' properties based on the identified causalities, and (ii) a graphical representation method to clear up the feedback form and the control law of the system (Chen et al., 2022). In this regard, (i) stock variables (level variables) represent the cumulative effects of a system, (ii) flow variables (rate variables) describe the rate at which the cumulative impact of the system changes, and (iii) auxiliary variables are intermediate variables in the conversion of information from stock variables to flow variables (Chen et al., 2022). The basic structure of a stock and flow diagram in addition to the diagramming notation used in System Dynamics modeling is illustrated in Figure 21. Clouds indicate (i) a source with an infinite capacity outside the model boundary, from which an inflow originates, and (ii) a sink with an infinite capacity to which the flow leaves the drains of the model boundary (Shams Esfandabadi, 2022).

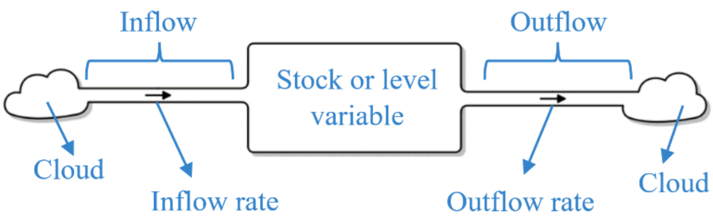


Figure 21. Sample structure of a stock and flow diagram.

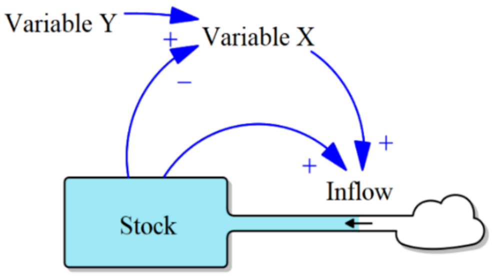
Stocks (level variables) accumulate or integrate materials over time with the rate of change according to the inflow and outflow. Hence, the sample stock and flow diagram illustrated in Figure 21 has the mathematical representation as in Equation 1, and the net rate of change of any stock can be defined as Equation 2.

$$\text{Stock (t)} = \int_{t_0}^{t} [\text{Inflow(s)} - \text{Outflow(s)}]\text{ds} + \text{Stock } (t_0) \qquad \text{Equation 1}$$

where Inflow(s) stands for the value of the inflow at any time s between the initial time t_0 and the current time t.

$$\frac{\text{d(Stock)}}{\text{dt}} = \text{Inflow (t)} - \text{Outflow (t)} \qquad \text{Equation 2}$$

Although stocks and flows are the only requirements for quantification and mathematical description of a system in System Dynamics modeling, intermediate or auxiliary variables are also used to aid clarity within the model (Shams Esfandabadi, 2022; Sterman, 2000). As an example, when the inflow rate depends on the stock and another variable, it can be modeled as a function of both the stock and the other variable (Shams Esfandabadi, 2022). Figure 22 shows a basic sample model containing auxiliary variables (variables X and Y) and presents its mathematical representation.



$$\text{Stock} = \text{INTEGRAL}\ (\text{Inflow}, \text{Stock}_{t_0})$$

$$\text{Inflow} = \text{Stock} \times \text{Variable X}$$

$$\text{Variable X} = {}^{\text{Variable Y}}/_{\text{Stock}}$$

Figure 22. A sample stock and flow diagram with auxiliary variables.

6.2.4. Step 4: model testing

Modelers need to test their model as soon as they write their first equation. However, in this step, the whole model developed should be carefully tested to build confidence in the quantitative model and its behavior. In this vein, modelers should check and confirm that (i) the assumed parameter values in the model are realistic, and (ii) the model behavior matches the expected feedbacks, to identify potential leverage points (Turner et al., 2016).

Several tests are available to validate the structure of the built model, such as dimensional consistency, behavior sensitivity, structure verification test, behavior reproduction test, and extreme conditions (Binti Hasan, 2019). Most importantly, the behavior sensitivity of the model should be tested. In this regard, model (i) should replicate the historical behavior, and (ii) should be tested under extreme conditions, even if the conditions may never happen in the real world (Sterman, 2000). Such testing is crucial to identify the flaws in the model and set the stage for an improved understanding of the dynamics of the system.

6.2.5. Step 5: policy design and evaluation

All the previous steps are taken to properly take this step. In fact, this step is the main reason behind System Dynamic modeling, since it delivers the main outcome of the model to the stakeholders who face challenges in the system. Once the model is tested and validated it can be used as a tool to propose proper policies for solving the problem and improvements in the system.

Policy design and evaluation in this step involve proposing ‘What-if?’ scenarios based on policy interventions to discover management potentials or leverage points, and future tipping points (Turner et al., 2016). In this regard, policy design is much more than just changing parameters’ values and should include new strategies, decision rules, and structures (Sterman, 2000). Moreover, according to Sterman (2000), the following criteria regarding policy design in System Dynamics modeling should be considered: (i) the robustness of policies and their sensitivity to uncertainties under different scenarios must be evaluated, and (ii) the potential interactions among policies should be considered since real systems are highly nonlinear and the impact of adopting policy combination is usually not the sum of their impacts alone.

Section IV

Model Development and Scenario Analysis

Section overview

This section presents the System Dynamics modeling process steps in three chapters.

- In the first chapter (Chapter 7), problem articulation and the formulation of hypotheses are presented.
- In the second chapter (Chapter 8), the formulation of the simulation model developed is carried out along with model testing.
- In the third chapter (Chapter 9), different scenarios are tested, and accordingly, proper policies are recommended.

Chapter 7: Problem Articulation and Dynamic Hypotheses Formulation

7.1. Food sharing business model selection

As mentioned in Chapter 4, digitally enabled FSPs are still new, and there is no common understanding of the business model of such platforms and how they work and create value within the food supply chain for involved stakeholders. However, according to Michelini et al. (2018) food sharing business models are categorized into three groups, including (i) the "sharing for money" business model, referring to a business-to-consumer for-profit business model to reduce FW and generate revenues simultaneously (ii) the "sharing for charity" business model, in which food is collected and distributed to non-profit organizations, and (iii) the "sharing for the community" business model, addressing peer-to-peer business models where consumers share food among each other.

The current thesis relies on the food sharing for money business model as the main case to develop a simulation model using System Dynamics. The main reasons behind considering this type of food sharing business model are, arguably, (i) this type of food sharing has gained much attention in terms of public engagement in comparison with other types, such as food sharing for charity, and food sharing for the community; (ii) this business model covers a wider range of consumers and retailers within the food supply chain; (iii) beyond FW reduction and environmental benefits achieved by this business model, since there are economic benefits for both distributors and consumers, the dynamics of such business models are more challenging than others, requiring further investigations.

7.2. Problem articulation: formulating research questions

The TGTG FSP users are dramatically increasing in different countries. Although this initiative was launched in 2016 in Copenhagen, it is now active in 17 countries, saving 250,000 meals every day (TGTG, 2022b). In some countries, such as Italy, the trend of TGTG adoption among potential consumers has been very sharp. Although TGTG has started its activities in Italy in March 2019, it reached 6.9 million users by the end of 2022 (TGTG, 2022a), which is notable. The main reasons behind such a rapidly increasing adoption rate might be (i) the willingness of people to prevent FW and help the environment through using such platforms, whose providers claim they are anti-waste warriors, and (ii) the economic attractiveness for some parts of the community, especially the vulnerable population who care about discounted prices offered by the points of sale through the TGTG app.

In this regard, the role of some drivers in the adoption of TGTG and its performance, such as word of mouth, marketing efforts for increasing public awareness, knowledge-enhancing activities for increasing knowledge of potential consumers, attractiveness characteristics for TGTG adoption and usage (e.g., price, environment friendliness, etc.), familiarity, and social exposure is still under-researched. Hence, in the current thesis, a System Dynamics model is developed to simulate the TGTG diffusion over time by 2060 to unfold how consumers will potentially adopt this FSP. Accordingly, the first question of this thesis is formulated as follows.

- **RQ1.** How would the diffusion of the TGTG food sharing app be in Italy by 2060?

In contrast with the increasing number of users, the average number of saved food boxes per user per year is quite low. For instance, in Italy, from March 2019 to the end of 2022, only 10 million foods (i.e., magic boxes) have been saved by 6.9 million TGTG users (TGTG, 2022a), which accounts for approximately less than 0.4 of a food box per user per year. Hence, the paradox of a highly increasing number of users with low effective usage of TGTG in terms of the number of foods saved per user per year calls for research. In other words, the contribution of FSPs to FW prevention and creating a circular food system is not clear and faces some challenges.

Moreover, while some believe that using such platforms potentially helps reduce FW, others argue that they can lead to a rebound effect and provide some extra lines of production and consumption. As a result, although the platform providers in the case of the food sharing for money business model (e.g., TGTG) generate revenue, the outcome does not effectively help FW management and CE transition in practice.

Considering all the different parts of the situation together, the potential of FSPs in preventing FW and supporting a circular food system over time is still lacking. Therefore, the second research question of the current thesis is formulated as follows:

- **RQ2.** To what extent the TGTG food sharing app can help FW prevention in a CE in Italy over time?

7.3. Dynamic hypothesis formulation

The dynamic hypothesis is a conceptual model highlighting the potential causalities within the system as a simple mind map that qualitatively analyzes the dynamic relationship among multiple factors of the system (Binti Hasan, 2019).

When it comes to introducing and launching new technologies and platforms, the adoption dynamics are complex and require a systems thinking approach to tackle the arising challenges. In this regard, several factors might influence the adoption of new technologies, platforms, and apps. According to Struben and Sterman (2008), subsidies and marketing programs in the long term play an important role in self-sustaining diffusion. In particular, Struben and Sterman (2008) in their simulation model for alternative fuel vehicle adoption showed that word of mouth from those not driving an alternative vehicle can highly stimulate diffusion. In another research, Shams Esfandabadi (2022) through developing a System Dynamics model to simulate the diffusion of carsharing platforms within the transport system highlighted the important role of knowledge-enhancing activities both for adults and under-aged people in the diffusion of carsharing and sustaining its market share.

TGTG has based its activities on four main pillars, including people, companies, schools, and politics (Fragapane and Mortara, 2022). On this basis, TGTG has targeted increasing knowledge of people regarding FW implications for societies and the environment to battle against FW. In this regard, (i) inspiring consumers to help with FW prevention by providing information and raising their awareness of the FW phenomenon, (ii) involving various food-related businesses, such as bakeries, restaurants, supermarkets, and hotels in FW reduction practices within different stages from food production to retail and consumption, (iii) organizing different classes and seminars in schools targeting FW information and awareness are among knowledge-enhancing activities of TGTG. Nevertheless, the impact of such activities on the adoption of TGTG and FW prevention is still lacking due to the novelty of the initiative and also the lack of reliable data.

Hence, since there is no diffusion model for food sharing apps in the literature yet, the dynamics of adoption for such platforms are still unexplored. Therefore, adopting the models developed by Struben and Sterman (2008) and Shams

Esfandabadi (2022), a System Dynamics model is developed in the current thesis to simulate the TGTG adoption and its effective usage by consumers to prevent FW. In this regard, three main dynamic hypotheses are formulated addressing marketing efforts and knowledge-enhancing activities. In this regard, potential dynamics of marketing efforts and knowledge-enhancing activities (both for adults and under-aged people) considering three criteria (i.e., start time, duration, and effectiveness) and their impacts on the TGTG diffusion and performance in terms of FW prevention are modeled.

Consequently, the main dynamic hypothesis in the current thesis targets marketing efforts and knowledge-enhancing activities to analyze whether knowledge-enhancement and marketing can affect the higher effectiveness of TGTG both in terms of users and food saved. The dynamic hypotheses are formulated as follows:

Dynamic hypothesis #1: marketing efforts can potentially affect the adoption of the TGTG app over time in terms of the number of users.

- The sooner the marketing efforts begin, the higher the diffusion level of TGTG would be.
- The longer the marketing efforts last, the higher the diffusion level of TGTG would be.
- The more intensive the marketing plans, the higher the diffusion level of TGTG.

Dynamic hypothesis #2: knowledge-enhancing activities for adult population can potentially affect the adoption of the TGTG app over time in terms of (1) the number of users, and (ii) effective usage of the TGTG app.

- The sooner the knowledge-enhancing activities begin, (1) the higher the diffusion level of TGTG would be, and (2) the more effective TGTG would be in terms of FW prevention.
- The longer the knowledge-enhancing activities last, (1) the higher the diffusion level of TGTG would be, and (2) the more effective TGTG would be in terms of FW prevention.
- The more intensive the knowledge-enhancing activities, (1) the higher the diffusion level of TGTG, and (2) the higher FW prevention through TGTG.

Dynamic hypothesis #3: knowledge-enhancing activities for under-aged people can potentially affect their adoption of the TGTG app over time in the future in terms of (1) the number of users, and (ii) effective usage of the TGTG app.

- The sooner the knowledge-enhancing activities for under aged people begin, (1) the higher the diffusion level of TGTG would be, and (2) the more effective TGTG would be in terms of FW prevention.
- The longer the knowledge-enhancing activities for under aged people last, (1) the higher the diffusion level of TGTG would be, and (2) the more effective TGTG would be in terms of FW prevention.
- The more intensive the knowledge-enhancing activities for under aged people, (1) the higher the diffusion level of TGTG, and (2) the higher FW prevention through TGTG.

Chapter 8: Simulation Model Formulation and Testing

8.1. Formulating the simulation model

In order to develop a model addressing the dynamics of the diffusion of the TGTG food sharing app in this research and estimate the considered circularity indicator accordingly, two innovation diffusion models have been considered as the fundamental frameworks for model development. The first model is the diffusion model developed by Struben and Sterman (2008), which is an extension of the basic Bass diffusion model of innovation adoption (Bass, 1969). This model accounts for endogenous word-of-mouth from adopters, and includes the effects of marketing and media (Mahajan et al., 2000), substitution among successive technologies (Norton and Bass, 1987), uncertainty about the innovation value (Kalish, 1985), and repurchases (Sterman, 2000). Furthermore, unlike Bass innovation diffusion model that generates an S-shaped growth curve for technology, this diffusion model incorporates additional diffusion patterns, including rise and demise, stagnation at low penetration levels, and fluctuations. The second model, developed by Shams Esfandabadi (2022), is an extension of the Struben and Sterman (2008) model for the diffusion shared platforms within the transportation sector. The development of the current simulation model for the diffusion of FSPs draws inspiration from both models, intertwining their principles and concepts.

While the present model shares certain similarities with the previously mentioned models, it significantly differs from both. The current model incorporates the concepts of customers' willingness to adopt technology and marketing activities, which are general concepts regarding the diffusion of technologies, from Struben and Sterman (2008), but it diverges by not considering the co-evolution of alternative technologies and infrastructure due to the distinct nature of digitally enabled FSPs. These platforms can experience rapid diffusion without specific infrastructure requirements, unlike durable products. Moreover, the current model draws from Shams Esfandabadi’s (2022) structure for educating the young population on product-service systems but differs in two main aspects. Firstly, it considers knowledge-enhancing activities for both under-aged individuals and adults to analyze scenarios aligned with TGTG's efforts against FW. Secondly, while Shams Esfandabadi's (2022) model focuses on the effect of knowledge-enhancing activities on technology adoption (e.g., becoming active users), the current model considers the impact of knowledge-enhancing activities on both technology adoption (i.e., becoming an FSP member) and user activities (i.e., ordering food bags). Additionally, although both core models address people's familiarity with technology, the structure proposed by Shams Esfandabadi (2022) is utilized with some modifications due to its relevance to product-service systems. On this basis, an extensively modified System Dynamics model is developed to simulate food sharing app diffusion, enabling estimation of not only the app's diffusion dynamics and app performance, but also its contribution to the CE and CO_2 emission reduction.

To provide a clear view of the dynamics considered in the developed model, the main feedback loops leading to the key dynamics are illustrated in Figure 23. The reinforcing loop R1 refers to the social exposure that leads to more adoption of the food sharing app. This loop indicates that higher social exposure, derived from both marketing efforts and effective contacts with app users, leads to heightened familiarity of people with the FSP. This, in turn, enhances the likelihood of individuals considering joining the app. Then, an increase in the number of app users leads to more social exposure and this positive loop continues. However, the more people are familiar with the FSP, the more they look for information and talk about it with other people (word-of-mouth), leading to a higher familiarity gain, as shown in loop R2. On the other hand, in the absence of sufficient exposure to the app or interactions with app users, individuals gradually lose their familiarity with the platform as it fades from their memory over time, as shown by the balancing loop B1.

Knowledge-enhancing programs can amplify people's understanding, awareness, and social exposure to digitally enabled FSPs and FW prevention. In this regard, since TGTG has some knowledge-enhancing webinars and educating programs planned for supermarket staff, companies, and schools, the effect of enhancing the knowledge of children and also adults on the adoption of the food sharing apps and the active usage of such platforms are also taken into account in the developed model. In fact, knowledge-enhancing programs not only bolster individuals' familiarity and enhance the attractiveness of joining the app, but also motivate them to leverage their app usage and more actively prevent food wastage. Finally, in addition to the amount of FW and CO_2 emission prevented; a circularity index is considered in the model to estimate the level of circularity of the TGTG food sharing app based on the amount of FW prevented.

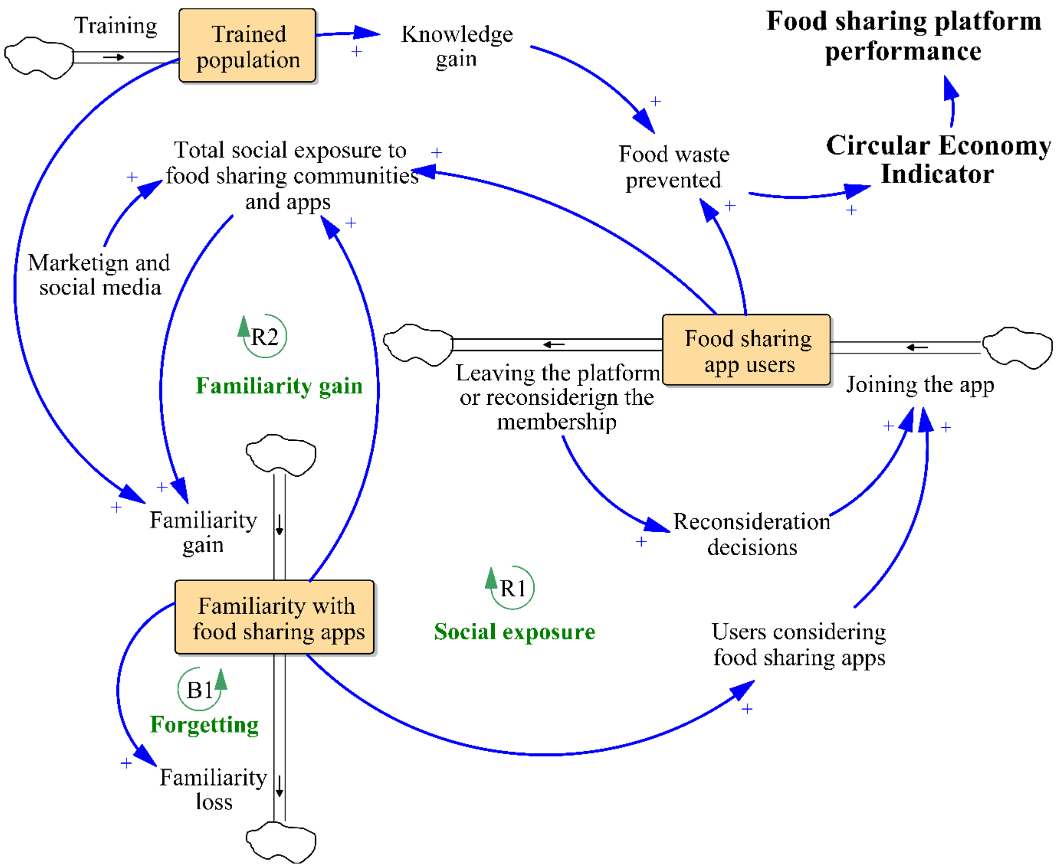


Figure 23. The conceptual model addressing key feedback loops in the developed model for the TGTG FSP diffusion.

However, the model is not limited to the loops mentioned. As shown in Figure 24, the developed model contains several stock and flow structures and auxiliary variables, generating dynamics through numerous loops. The model combines four main elements, including:

(i) the effect of knowledge enhancement programs on the dynamics of the well-informed population regarding FW prevention and CE,

(ii) the accumulation of consumer familiarity from marketing, knowledge-enhancing programs, and word-of-mouth, leading to the adoption of food sharing apps,

(iii) the dynamics linked with the adoption of food sharing apps, and

(iv) the causalities referring to the estimation of FW, CO_2 emission prevented, FSP performance, and the CE indicator.

These elements are presented in sub-sections 8.1.3 to 8.1.4, respectively. In order to keep brevity and provide useful information at the same time, some of the important equations used in the model are presented in each of these sub-sections along with the description of the causalities. Moreover, the data used to calibrate the model is presented at the end of each sub-section.

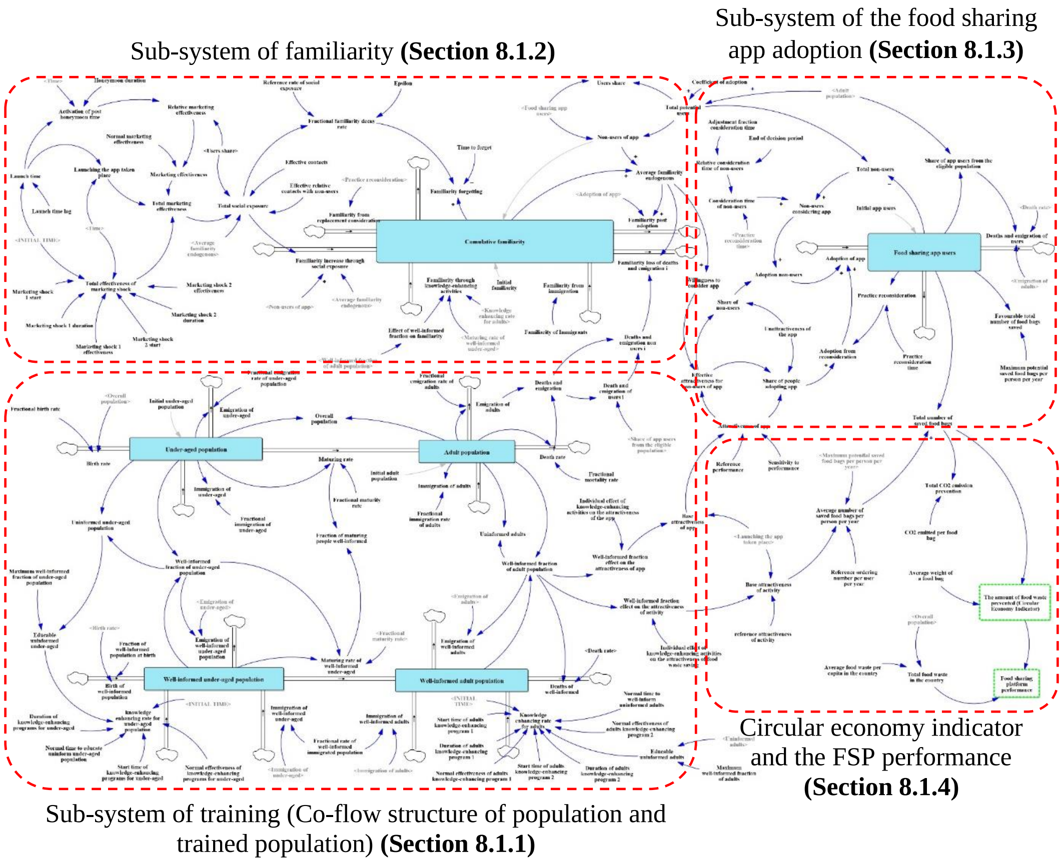


Figure 24. The key feedback loops in the developed model (this figure is just for illustrative purposes; for details, please refer to Figures 25-28).

Data plays a key role in System Dynamics simulation. Three types of data, including numerical data (e.g., time series, cross-sectional data, etc.), written data (e.g., media reports, operational procedures, etc.), and mental data (e.g., people's impressions, people's understanding of the system, decision-making process, etc.) are required for the development of a System Dynamics model (Sterman, 2000). While numerical and written data can be accessible, direct access to mental data is impossible. However, as ignoring soft variables and restricting the variables to those with numerical data leads to the development of incomplete and wrong models (Forrester, 1961), interviews, observations, or any other possible method should be applied to extract this type of data. Nevertheless, if time and cost restrictions do not allow the modeler to run surveys or interviews to quantify soft variables, the values of these parameters can be estimated through judgment (Sterman, 2000), and in this case, the behavior pattern of the model deserve more attention in comparison with the exact value of the variable at a specific time point (Hekimoğlu and Barlas, 2010). Therefore, in this research, where numerical data is available, this data has been used in the model; otherwise, the values of the parameters have been estimated based on judgment, and the behavior of the model has been checked to be reasonable.

8.1.1. Knowledge enhancement in the population

The research conducted on FSPs with food sharing for money business model reveals that the main motivation behind using these apps is primarily economic considerations rather than environmental motivations (Pisoni et al., 2022). Hence, changing individuals' mindset concerning environmental issues necessitates extensive endeavors and knowledge-enriching initiatives that require a significant amount of time. In this regard, programs and activities aimed at enhancing knowledge, such as webinars for knowledge-enhancement, the development of educational materials for schools and colleagues, massive online courses, mentorship programs, and corporate knowledge-enhancing initiatives, can substantially contribute to raising public awareness and knowledge about the profound consequences of FW on the environment, society, and economy. The effective promotion of science-based environmental activism requires the combined forces of technological innovation and active societal learning (Papachristos and Struben, 2020). Effective diffusion of food sharing apps also requires appropriate societal learning, a huge part of which can happen through knowledge-enhancing programs. As stated in Chapter 5, the "pact against food waste" initiative launched by TGTG has also taken into account the potential impact of knowledge-enhancing activities on society by highlighting the knowledge-enhancing webinars for the supermarkets and companies' staff and preparing knowledge-enhancing materials for schools.

The term "well-informed" population in this research denotes the segment of the population that has received adequate education regarding FW and its effects on various aspects of sustainability, encompassing the environment, society, and economy. On the other hand, the "uninformed" population refers to individuals who are unaware of the profound consequences and implications of the FW crisis, as well as the primary purpose of using FSPs. This purpose involves reducing FW and transitioning towards a CE, rather than being solely driven by factors like lower prices. On this basis, "knowledge-enhancing" programs and plans refer to all educational activities that support the transitioning of the "uninformed" population into the "well-informed" category.

In order to analyze the potential role of training and educating people in the adoption and usage of food sharing apps, a co-flow structure (a parallel stock and flow structure) has been developed to model the dynamics of the population and the dynamics of the well-informed population.

As illustrated in Figure 25, the flow of the population contains a simple age structure with two age cohorts referring to the under-aged (less than 18 years of age) and adult (18 years of age and older) populations. Similarly, the flow of the well-informed population also includes these two age cohorts, but specifically for the well-informed population. In each of the population stocks in these flows, the assumption of perfect mixing in age groups based on Sterman (2000) is made.

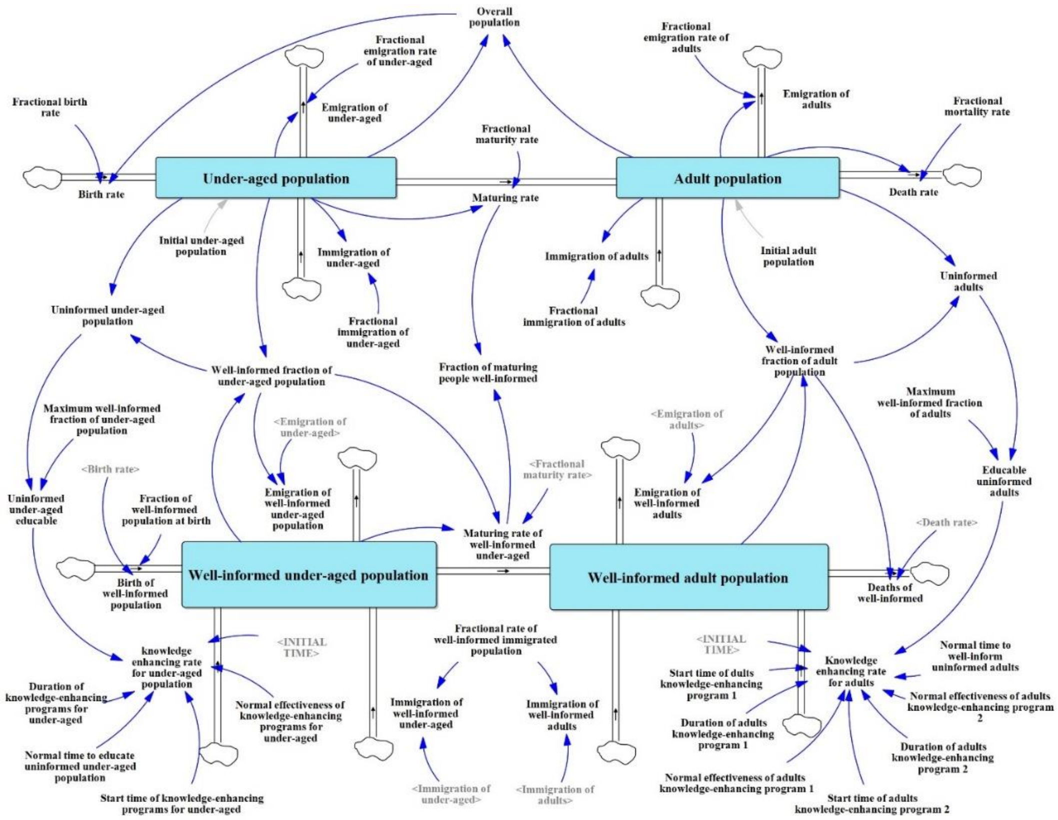


Figure 25. The co-flow structure addressing knowledge enhancement in the population.

In order to maintain simplicity and clarity within the model, the birth rate is assumed to be proportional to the total population, and a general death rate based on the overall death rate of the population is considered. Based on the inflows and outflows of the under-aged and adult population stocks, the population in these two age cohorts can be formulated as in Equation 3 and Equation 4, respectively.

$$\mathrm{UPOP(t)} = \int_{t_0}^{t} (\mathrm{BR} + \mathrm{IMUPOP} - \mathrm{EMUPOP} - \mathrm{MR})\mathrm{dt} + \mathrm{IUPOP}\ (t_0) \qquad \text{Equation 3}$$

$$\mathrm{APOP\ (t)} = \int_{t_0}^{t} (\mathrm{MR} + \mathrm{IMAPOP} - \mathrm{EMAPOP} - \mathrm{DR})\mathrm{dt} + \mathrm{IAPOP}\ (t_0) \qquad \text{Equation 4}$$

where:

BR: Birth rate

DR: Death rate

UPOP: Under-aged population

APOP: Adult population

IUPOP: Initial under-aged population

IAPOP: Initial adult population

IMUPOP: Immigration of the under-aged population

IMAPOP: Immigration of the adult population

EMUPOP: Emigration of the under-aged population

EMAPOP: Emigration of the adult population

MR: Maturity rate

The initial under-aged population and initial adult population refer to the population of these age cohorts at the time t_0 of the simulation (the year 2015). Furthermore, immigration and emigration rates for the under-aged and adult population are proportional to the population in their corresponding age cohorts based on their corresponding fractional immigration and emigration rates. Moreover, maturity rate refers to the growth of under-aged youth and their transition from the under-aged population age segment to the adult population age segment and can be found by multiplying the under-aged population by its corresponding fractional maturity rate, which is the average time required for an individual to leave a younger age cohort and enter the older one (Mielczarek and Zabawa, 2016). Therefore, the fractional maturity rate is assumed to be the inverse of the age cohort's length (Vahidi Monfared and Moini, 2019), which is 18 in the current model. On this basis, the maturing rate is calculated as follows:

$$\mathrm{MR} = \mathrm{UPOP} \times \mathrm{FMR} \qquad \text{Equation 5}$$

where:

FMR: Fractional maturity rate = $^{1}/_{18}$

In parallel with the population flow structure, the well-informed population structure is formulated, which has two inflows for knowledge enhancement among under-aged and adult populations in addition to birth, death, maturing, emigration, and immigration rates. The well-informed under-aged population and well-informed adult population stocks can be formulated as in Equation 6 and Equation 7, respectively.

$$\mathrm{WUPOP}\ (\mathrm{t}) = \int_{\mathrm{t_0}}^{\mathrm{t}} (\mathrm{BWPOP} + \mathrm{IMWUPOP} + \mathrm{KRUPOP} - \mathrm{EMWUPOP} - \mathrm{MRWU})\mathrm{dt} \qquad \text{Equation 6}$$

$$\mathrm{WAPOP}\ (\mathrm{t}) = \int_{\mathrm{t_0}}^{\mathrm{t}} (\mathrm{IMWAPOP} + \mathrm{MRWU} + \mathrm{KRAPOP} - \mathrm{DWPOP} - \mathrm{EMWAPOP})\mathrm{dt} \qquad \text{Equation 7}$$

where:

WUPOP: Well-informed under-aged population

WAPOP: Well-informed adult population

BWPOP: Birth of well-informed population $= 0$

IMWUPOP: Immigration of well-informed under-aged population

EMWUPOP: Emigration of well-informed under-aged population

KRUPOP: Knowledge enhancement rate for the under-aged population

MRWU: Maturing rate of well-informed under-aged population

IMWAPOP: Immigration of well-informed adult population

KRAPOP: Knowledge enhancement rate for the adult population

DWPOP: Deaths of well-informed population

EMWAPOP: Emigration of the well-informed adult population

The birth of the well-informed population is set to zero since no body is born well-informed. However, this rate has been considered in the model to keep the co-flows similar. Emigration of well-informed under-aged and adult populations follow Equation 8 and Equation 9, respectively.

$$\mathrm{EMWUPOP} = \mathrm{WFUPOP} \times \mathrm{EMUPOP} \qquad \text{Equation 8}$$

$$\mathrm{EMWAPOP} = \mathrm{WFAPOP} \times \mathrm{EMAPOP} \qquad \text{Equation 9}$$

where:

WFUPOP: Well-informed fraction of the under-aged population

WFAPOP: Well-informed fraction of the adult population

Knowledge enhancement rates for the under-aged and adult populations are affected by start time, duration, and effectiveness of knowledge-enhancing programs, as well as the normal time to increase the knowledge of the uninformed population, and the educable uninformed portion of the population for each of these age segments. Knowledge-enhancing activities are considered to start at a specific time with specified effectiveness and last for a particular period. Therefore, in order to formulate the equations referring to these rates, the function STEP in the Vensim software has been used. STEP function returns zero until a specific time and after that, jumps to a specified value[*]. Equation 10 and Equation 11 present the formulation of the knowledge enhancement rate for the under-aged population and the knowledge enhancement rate for adults, respectively. It should be noted that as according to the TGTG's "pact against food waste" (TGTG, 2021), knowledge-enhancement among adults has already been started (since 2021), two different sets of variables for knowledge enhancement have been considered for adults in order to both simulate the effect of the current knowledge-enhancing activities and test scenarios regarding changes in the knowledge enhancement activities in future. However, depending on the FSPs considered while using this simulation model, the number of programs can increase or decrease.

$$\begin{aligned} \mathrm{KRUPOP} = (STEP\ (1, \mathrm{INITIAL\ TIME} &\\ +\ \mathrm{ESU}) - \mathrm{STEP}\ (1, \mathrm{INITIAL\ TIME}\ +\ \mathrm{ESU} &\\ +\ \mathrm{EDU}))\ \times\ \mathrm{EUU}\ \times\ \mathrm{NEKU}/\ \mathrm{NEUU} & \end{aligned} \quad \text{Equation 10}$$

$$\begin{aligned} \mathrm{KRAPOP} = (\mathrm{STEP}\ (1, \mathrm{INITIAL\ TIME} +\ \mathrm{KSA1}) &\\ - \mathrm{STEP}\ (1, \mathrm{INITIAL\ TIME} +\ \mathrm{KSA1} &\\ +\ \mathrm{KDA1})) \times \mathrm{EUA} \times \mathrm{NEKA1}/\mathrm{NEUA} &\\ + (\mathrm{STEP}\ (1, \mathrm{INITIAL\ TIME} +\ \mathrm{KSA2}) &\\ - \mathrm{STEP}\ (1, \mathrm{INITIAL\ TIME} +\ \mathrm{KSA2} &\\ +\ \mathrm{KDA2})) \times \mathrm{EUA} \times \mathrm{NEKA2}/\mathrm{NEUA} & \end{aligned} \quad \text{Equation 11}$$

where:

[*] For instance, the equation $X = 1000 + STEP\ (300{,}10)$ returns 1000 until time 10, and after that jumps to 1300.

ESU: Education start time for under-aged

EDU: Education duration for under-aged

NEKU: Normal effectiveness of knowledge-enhancing programs for under-aged

NEKA: Normal effectiveness of knowledge-enhancing programs for adults

NEUU: Normal time to educate the uninformed under-aged population

EUU: Educable uninformed under-aged population

KSA1: Knowledge-enhancing program #1 start time for adults

KSA2: Knowledge-enhancing program #2 start time for adults

KDA1: Knowledge-enhancing program #1 duration for adults

KDA2: Knowledge-enhancing program #2 duration for adults

NEKA1: Normal effectiveness of knowledge-enhancing program #1 for adults

NEKA2: Normal effectiveness of knowledge-enhancing program #2 for adults

EUA: Educable uninformed adults

NEUA: Normal time to educate the uninformed adult population

Although both age cohorts receive training and use knowledge-enhancing programs (with different times and effectiveness), only adults are eligible to join and use the TGTG FSP. However, when the under-aged population is well-informed, this knowledge can be transferred to the adult age cohort through the growth and maturity of the under-aged population. The well-informed fraction of the adults are expected to be more willing to join and use the FSP, as the attractiveness of the app and its usage can increase through knowledge enhancement. Similar to the maturity rate in the population flow, the well-informed under-aged maturing rate is linked with a fractional maturity rate, which is the inverse of the age cohort's length and is $1/_{18}$ in this model. Therefore, the maturing rate of well-informed under-aged can be formulated as:

$$\text{MRWU} = \text{WFUPOP} \times \text{WUPOP} \times \text{FMR} \qquad \text{Equation 12}$$

The initial values of the population stocks, referring to the people of 0-17 years old and adults of more than 18 years of age in 2015, were set based on the available data on PopulationPyramid (2022), equal to approximately 9,783,272 and 50,795,216 people, respectively, summing up to an overall population of 60,578,488. The overall population of the country at the beginning of 2022 was 59,030,133, consisting of 9,218,914 people less than 18 and 49,811,219 people with at least 18 years of age (ISTAT, 2022) and it is projected that the population will experience a reduction by 2060. Based on the available population projections in Italy, in 2060 the population of the country will be in a range from approximately 46 to 56 million, with a lower limit of 90% of 46,151,752, a median of 50,905,715, and an upper limit of 90% of 56,053,197 (ISTAT, 2022).

Since the current research aims to show the main diffusion dynamics in the model, slight fluctuations in the population during the simulation period are not of interest. Therefore, the population parameters are set in a way that the model generates a decreasing trend in the overall population close to the observed trend from 2015 to 2022 in Italy and the projected population for 2060. In this regard, the fractional birth rate, the fractional death rate, the fractional emigration rate for young and old generations, and the fractional immigration rate for the two generations are set in such a way that they fall within the range of minimum and maximum observed or forecasted values until 2060. On this basis, the values considered for these variables are as reported in Table 17.

The simulated values in the model are very close to the available data and projected values in the official database of I.Stat (ISTAT, 2022). For instance, the simulation through the developed model shows an overall population of 59,026,300 for the year 2022, consisting of people younger than 18 years and 49,916,200 people older than 18 years, which is very close to the available statistics. Besides, the developed model estimates the population of 2060 to be 50,932,000, which is very close to the median of the projected population for this year in the I.Stat database (the breakdown of the projected population in terms of age is not available for comparison with the simulated values).

Table 17. Values used for the exogenous variables in the sub-system of knowledge enhancement in population.

Variable	Unit	Value	Reference/Justification
Under-aged population in 2015	Person	9,783,272	Estimation based on PopulationPyramid (2022)
Population of adults in 2015	Person	50,795,216	Estimation based on PopulationPyramid (2022)
Fractional birth rate	$1/year$	0.007	Estimation based on I.Stat (2022)
Fractional death rate	$1/year$	0.0134	Estimation based on I.Stat (2022)
Fractional immigration rate of under-aged population	$1/year$	0.004	Estimation based on I.Stat (2022)
Fractional immigration rate of adult population	$1/year$	0.004	Estimation based on I.Stat (2022)
Fractional emigration rate of under-aged population	$1/year$	0.003	Estimation based on I.Stat (2022)
Fractional emigration rate of adult population	$1/year$	0.0035	Estimation based on I.Stat (2022)
Normal time to inform and educate children	Year	10	Assumption
Normal time to inform and educate adults	Year	10	Assumption

8.1.2. Familiarity with food sharing platforms

A crucial factor in the adoption of technology is the potential users' willingness to include it in their consideration set, which necessitates a certain level of familiarity (Struben and Sterman, 2008). Therefore, familiarity plays a key role in the diffusion of food sharing apps. The familiarity sub-system depicted in Figure 26 draws upon the framework developed by Shams Esfandabadi (2022). Their work acknowledged the concurrent spread of multiple platforms and considered the spillover effect between these platforms, which is suggested to be considered also in the current model if multiple PSFs are competing in the market being studied. However, in our current study, our attention is primarily directed towards the diffusion of a single FSP, which holds a remarkable reputation and dominance in Italy, surpassing other similar but less extensive apps by a significant margin. Consequently, we have chosen to exclude the incorporation of the spillover effect within the presented model.

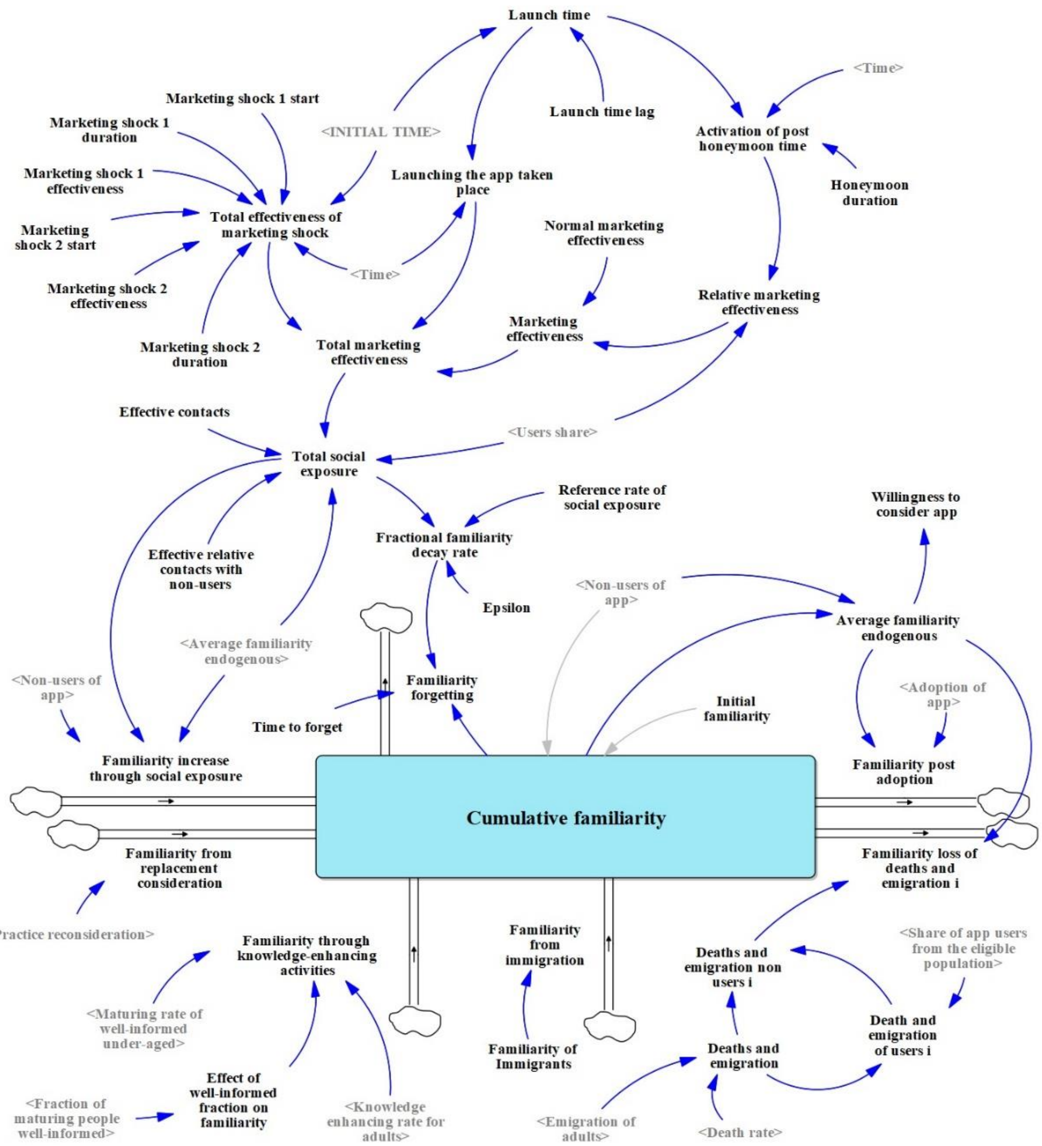


Figure 26. The Sub-system of familiarity with the FSP.

According to the inflows and outflows of the familiarity stock illustrated in Figure 26, cumulative familiarity increases through social exposure, familiarity gaining when someone is at the replacement consideration stage, maturing the well-informed children, and the transfer of familiarity through immigration (the latter two are linked with the population sub-system discussed in section 8.1.1). A portion of this increase is cancelled out by familiarity decrease through death and emigration of the well-informed people, loss of familiarity after making the adoption decision, and forgetting. On this basis, cumulative familiarity at the population level can be formulated as in Equation 13.

$$\mathrm{CF} = \int_{t_0}^{t} (\mathrm{FSE} + \mathrm{FK} + \mathrm{FIM} + \mathrm{FR} - \mathrm{FDEMU} - \mathrm{FP} - \mathrm{FF})\,dt + (\mathrm{NU} \times \mathrm{IF})\,(t_0) \qquad \text{Equation 13}$$

where:

CF: Cumulative familiarity

FSE: Familiarity increase through social exposure

FK: Familiarity increase through knowledge-enhancing activities

FIM: Familiarity increase through immigration

FR: Familiarity increase from replacement consideration

FDEMU: Familiarity loss resulting from deaths and emigration of app users

FP: Familiarity loss post adoption

FF: Familiarity loss through forgetting

NU: Non-users of the app

IF: Initial familiarity

Knowledge-enhancing activities can increase the familiarity of people with food sharing apps, hence, familiarity through knowledge-enhancing activities can be formulated as in Equation 14. Furthermore, familiarity from replacement consideration is affected by the reconsideration of the app adoption; and familiarity post adoption is estimated based on Equation 15.

$$\mathrm{FK} = \mathrm{EWFAF} \times (\mathrm{MRWU} + \mathrm{KRAPOP}) \qquad \text{Equation 14}$$

$$\mathrm{FP} = \min\left(1, {}^{\mathrm{CF}}/_{\mathrm{NU}}\right) \times \mathrm{AD} \qquad \text{Equation 15}$$

where:

EWFAF: Effect of the well-informed fraction of the adult population on familiarity

AD: App adoption

Familiarity increase through social exposure depends on the total social exposure and is formulated as in Equation 16.

$$\mathrm{FSE} = \mathrm{TSE} \times \mathrm{NU} \times (1 - \mathrm{Min}(1, (\mathrm{CF} / \mathrm{NU}))) \qquad \text{Equation 16}$$

where:

TSE: Total social exposure

Besides, total social exposure arises from marketing activities, direct word-of-mouth about the app through contacts with its users, and indirect word-of-mouth about the app with its non-users. Hence, the total social exposure can be formulated as:

$$\mathrm{TSE} = \mathrm{TME} + \mathrm{EC} \times (\mathrm{US} + \mathrm{ECNU} \times \mathrm{AFE} \times (1 - \mathrm{US})) \qquad \text{Equation 17}$$

where:

TME: Total marketing effectiveness

EC: Effective contacts

US: Users share

ECNU: Effective relative contacts with non-users

AFE: Average familiarity endogenous

Total marketing effectiveness is taken into account post- app launch and includes both regular marketing efforts and especial marketing plans for specific periods (referred to as marketing shock in this thesis). On this basis, total marketing effectiveness can be formulated as:

$$\mathrm{TME} = \mathrm{L} \times (\mathrm{ME} + \mathrm{TEMS}) \qquad \text{Equation 18}$$

where:

L: Launch of the app ($L = 0$ before the launch of the app and $L = 1$ after the launch of the app)

ME: Marketing effectiveness

TEMS: Total effectiveness of the marketing shock

The effectiveness of a regular marketing plan depends on its relative effectiveness. Besides, starting from the launch time of the app, a specific period called “honeymoon” is considered during which marketing effectiveness is not endogenous. The total effectiveness of the intensive marketing campaigns (herein, referred to as marketing shocks) depends on their starting point, duration, and effectiveness. Multiple marketing shocks may exist in the system, depending on the market and the FSPs being studied. In order to address the dynamics related to the sharp increase in the number of TGTG users during its activity period in Italy, two sets of marketing shocks are included in the model, one to address the current intensive marketing activities (shock #1), and the other for analyzing potential scenarios (shock #2). Therefore, the total effectiveness of marketing shock can be formulated as:

$$\begin{aligned} \mathrm{TEMS} = {} & \mathrm{IF\ THEN\ ELSE\ (Time - INITIAL\ TIME} \\ & < \mathrm{MSS1, 0, IF\ THEN\ ELSE\ (Time - INITIAL\ TIME} \\ & \geq \mathrm{MSD1 + MSS1, 0, MSE1)) + IF\ THEN\ ELSE\ (Time} \\ & - \mathrm{INITIAL\ TIME} \\ & < \mathrm{MSS2, 0\ , IF\ THEN\ ELSE\ (Time - INITIAL\ TIME} \\ & \geq \mathrm{MSD2 + MSS2, 0, MSE2))} \end{aligned} \quad \text{Equation 19}$$

where:

MSS1: Marketing shock 1 start

MSS2: Marketing shock 2 start

MSE1: Marketing shock 1 effectiveness

MSE2: Marketing shock 2 effectiveness

MSD1: Marketing shock 1 duration

MSD2: Marketing shock 2 duration

Familiarity with a technology gradually declines over time unless it is refreshed; this decay process is highly non-linear, and if exposure to the technology is infrequent and insufficient, familiarity diminishes rapidly (Struben, 2006). However, higher exposure decreases the decay rate until a highly frequent exposure is formed and familiarity decay does not continue. Hence, according to Struben

(2006), familiarity loss through forgetting and fractional familiarity decay rate are formulated as follows:

$$\mathrm{FF} = \mathrm{FFDR} \times \mathrm{CF} / \mathrm{TF} \qquad \text{Equation 20}$$

$$\mathrm{FFDR} = \mathrm{Min}\ (1, \mathrm{Max}\ (0, \varepsilon \times \mathrm{RRSE} + 0.5 - \varepsilon \times \mathrm{TSE})) \qquad \text{Equation 21}$$

where:

FFDR: Fractional familiarity decay rate

TF: Time to forget

RRSE: Reference rate of social exposure

More details on the causalities in this sub-system can be seen in Figure 26. Besides, values used for the main exogenous variables in the base run of the model are reported in Table 18.

Table 18. Values used for the exogenous variables in the sub-system of familiarity.

Variable	Unit	Value	Reference/ Justification
Launch time lag	Year	4	TGTG was launched in 2019, while the simulation period starts in 2015.
Honeymoon duration	Year	10	Assumption
Effective relative contacts with non-users	dmnl[†]	0.25	(Struben, 2006)
Effective contacts	$dmnl/_{year}$	0.3	(Struben, 2006)
Reference rate of social exposure	$1/_{year}$	0.05	(Struben, 2006)
Epsilon	Year	20	(Struben, 2006)
Normal marketing effectiveness	$dmnl/_{year}$	0.01	Based on model calibration
Time to forget	Year	1	Assumption

[†] Dimensionless

Familiarity of immigrants	$Person/_{year}$	0	It is assumed that immigrants are not familiar with food sharing apps.

8.1.3. Food sharing app adoption

Consumer acceptance of a new technology plays a key role in its successful diffusion and sustained adoption (Struben, 2006). Therefore, the success of a digitally enabled FSP in terms of diffusion can be evaluated by considering its users. While joining a platform does not guarantee active usage of the app for ordering food bags, the absence of data to distinguish between TGTG app members and users leads to the assumption that membership equates to active app usage.

Figure 27 shows the stock referring to food sharing app users, its inflow and outflows, and also other variables affecting the dynamics in this stock. As can be seen in this figure, the number of food sharing app users increases with the growth of users' adoption and decreases by the emigration or deaths of users and also practice reconsideration of the users. Since food is not a durable product and people can easily join and leave FSPs at any time due to any reason, it is assumed that the users of such apps reconsider their membership after a while, leaving this stock. If they decide to continue using the app, they will be considered as a user again by adopting it and if they decide to leave the platform, they become a non-user. On this basis, the following equations are formulated:

$$\mathrm{U}\ (\mathrm{t}) = \int_{\mathrm{t}_0}^{\mathrm{t}} (\mathrm{AD} - \mathrm{PR} - \mathrm{DEMU})\mathrm{dt} + \mathrm{IU}\ (\mathrm{t}_0) \qquad \text{Equation 22}$$

$$\mathrm{AD} = \mathrm{ANU} + \mathrm{AR} \qquad \text{Equation 23}$$

$$\mathrm{PR} = \mathrm{U}/\mathrm{PRT} \qquad \text{Equation 24}$$

$$\mathrm{DEMU} = (\mathrm{SUPOP}) \times (\mathrm{DR} + \mathrm{EMAPOP}) \qquad \text{Equation 25}$$

where:

DEMU: Deaths or emigration of users

PR: Practice reconsideration

PRT: Practice reconsideration time

IU: Initial app users

ANU: Adoption by non-users

AR: Adoption from reconsideration

SUPOP: Share of app users from the eligible population

The initial number of app users in Equation 22 is set to zero because in 2015, which is the initial simulation time (t_0), TGTG was not launched yet, and there was no user of this platform in Italy. Furthermore, the death rate and emigration of people older than 18 years of age (Emigration of adults) are linked with the population sub-system that is already discussed in section 8.1.1. Adoption from reconsideration by users can be formulated as:

$$\mathrm{AR} = \mathrm{SA} \times \mathrm{PR} \qquad \text{Equation 26}$$

where SA, referring to the “share of people adopting apps”, is meant to be the share of people who have already been users of any competitive FSP, if available, who can also switch between apps. However, since only TGTG food sharing app in the Italian market is available and considered in this research, simpler forms of equations are presented and discussed. Therefore, SA can be formulated as:

$$SA = \frac{AA[\text{for users}]}{UAA + AA\,[\text{for users}]} \qquad \text{Equation 27}$$

where:

AA: Attractiveness of the app

UAA: Unattractiveness of the app (i.e., the reluctance of people to use food sharing apps and change their behavior regarding food consumption and wasting).

Non-users of the app have the opportunity to reevaluate their behavior within predefined time intervals and may opt to start considering its usage. Nonetheless, it is also assumed that if an individual does not choose to adopt the app within a certain number of years, they will never become a user. Hence:

$$NUC = TNU/CTNU \qquad \text{Equation 28}$$

$$CTNU = PRT \times RCTNU \qquad \text{Equation 29}$$

where:

NUC: Non-users considering the app

TNU: Total non-users of any food-sharing app of a similar type (which is equal to NU for the considered case in this research)

CTNU: Consideration time of non-users

RCTNU: Relative consideration time of non-users

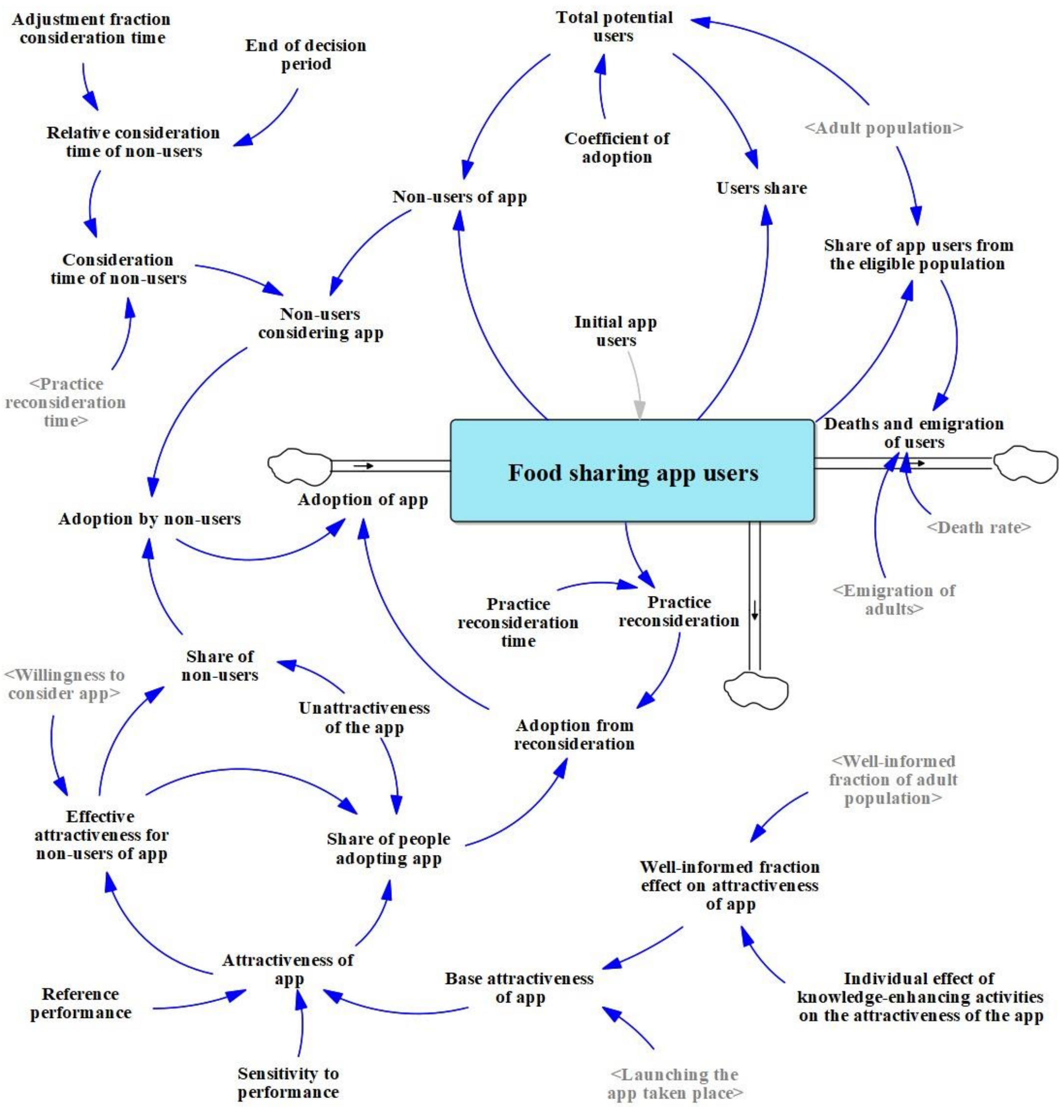


Figure 27. The sub-system of the food sharing app adoption.

Furthermore, it is important to note that not all adult family members should be assumed as potential users of the food sharing app, even though they are eligible to join (older than 18 years of age). Even if all adults in a family do join the app, their individual rate of ordering food bags may be lower compared to a scenario with fewer family members as app users. Additionally, it is common for some individuals to choose not to become users of the food sharing app for various reasons. To address this, a coefficient of adoption has been incorporated into the model, allowing for a reasonable portion of the adult population to be considered as potential users. Therefore, the number of total potential users is calculated as follows:

$$\mathrm{TPU} = \mathrm{APOP} \times \mathrm{CA} \qquad \text{Equation 30}$$

where:

TPU: Total potential users

CA: Coefficient of adoption

Similar to any other technology, the adoption of a food sharing app depends on its attractiveness to people. This attractiveness can result from the effect of the app diffusion on the perceived performance and the willingness to consider the app that is affected by the marketing activities and social exposure. Therefore, effective attractiveness for non-users of the app and attractiveness of the app are formulated as follows:

$$\mathrm{EANU} = \mathrm{WTC} \times \mathrm{AA}\ [\text{for non\_users}] \qquad \text{Equation 31}$$

$$\mathrm{AA} = \mathrm{BA} \times e^{\mathrm{STP} \times (1/\mathrm{RP} - 1)} \qquad \text{Equation 32}$$

where:

EANU: Effective attractiveness for non-users of the app

WTC: Willingness to consider the app

BA: Base attractiveness of using the app

STP: Sensitivity to performance

RP: Reference performance

Increasing people's knowledge about food sharing apps and the positive outcomes of FW prevention can increase the attractiveness of these platforms. Hence, based on Shams Esfandabadi (2022), the base attractiveness of using the food sharing app can be formulated as Equation 33, in which an increased attractiveness of using the app has been considered for the well-informed people after the FSP is launched.

$$\mathrm{BA} = ((1 - \mathrm{WTFAPOP}) + (\mathrm{WTFAPOP} \times \mathrm{IEEA})) \times \mathrm{L} \qquad \text{Equation 33}$$

where:

IEEA: Individual effect of education on the attractiveness of the app

In order to calibrate the model to fit the problem in this research, the values as presented in Table 19 have been used for the exogenous variables. It should be noted that based on the 2011 census data, which is the most recent census in Italy, 24,611,766 families live in this country with an average number of 2.4 persons per family (ISTAT, 2011). Based on the explanations provided above, it is assumed that a maximum of 80% of the population over 18 years of age can be potential users of food sharing apps. This will result in a maximum potential user of around 40 million, which is logical if compared with the number of families in the country. Furthermore, since accurate data about the number of TGTG app users over time is not available, referring to the available data by the end of 2022 in Italy (TGTG, 2022a), the model is calibrated such that the simulated number of users in 2022 becomes close to 6.9 million people.

Table 19. Values used for the exogenous variables in the sub-system of the food sharing app adoption.

Variable	Unit	Value	Reference/ Justification
Co-efficient of adoption	dmnl	0.8	Presented analysis in the current section
Initial app users	Person	0	TGTG was not launched in Italy in 2015 (t_0).
Practice reconsideration time	Year	1.5	Assumption
End of decision period	Year	50	Assumption
Unattractiveness of the app	dmnl	1.2	Based on model calibration
Reference performance	dmnl	1	Assumption
Sensitivity to performance	dmnl	1.5	Assumption and model calibration
Individual effect of knowledge-enhancing activities on attractiveness of the app	dmnl	2.5	Assumption and model calibration

8.1.4. Circular economy indicator and the food sharing platform performance

According to the Circular Economy Monitoring Framework announced by the European Commission, ten overarching indicators of the CE have been categorized into five groups, including production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability and resilience (European Commission, 2018). Since the focus of our research is on FW prevention at the consumption level within the food supply chain, we have considered the amount of FW prevented (corresponding to the FW indicator in the waste management category) as the main CE indicator to evaluate the performance of an FSP.

As stated in Chapter 5, the evaluation of the TGTG FSP success in this thesis has been analyzed by considering both the number of users and the amount of FW prevented. The dynamics in the number of users is estimated through the sub-system presented in section 8.1.3. The amount of FW prevented is a function of both the number of users and the amount of food they save. Therefore, the total number of saved food bags is estimated by using Equation 34.

$$\mathrm{TSFB} = \mathrm{U} \times \mathrm{ASFBPY} \qquad \text{Equation 34}$$

where:

TSFB: Total number of saved food bags

ASFBPY: average number of saved food bags per user per year

The average number of food bags a person saves per year is affected by the attractiveness of using the app for ordering food bags. However, this number cannot always be increasing, since it is not logical to order surprise bags from food sharing apps throughout the entire year. Hence, considering an upper bound for the average number of saved food bags and using the IF THEN ELSE[‡] function of the Vensim software, this variable can be formulated as:

$$\mathrm{ASFBPY} = \mathrm{IF\ THEN\ ELSE}\ (\ (\mathrm{BAO} \times \mathrm{RONUP}) \leq \mathrm{MFBPY}, (\mathrm{BAO} \times \mathrm{RONUP}), \mathrm{MFBPY}) \qquad \text{Equation 35}$$

where:

BAO: Base attractiveness of activity (ordering food bags)

RONUP: Reference ordering number per user per year

MFBPY: Maximum potential saved food bags per user per year

[‡] The equation $X = IF\ THEN\ ELSE\ (A, B, C)$ in Vensim simply conveys:
$X = \ if\ A, then\ B;\ otherwise\ C.$

Based on the causalities illustrated in Figure 28, the attractiveness of FW prevention activities in the platform after it is launched can be formulated as:

$$\mathrm{BAO} = (\mathrm{RAO} + \mathrm{EWFAAO}) \times \mathrm{L} \qquad \text{Equation 36}$$

where:

RAO: Reference attractiveness of activity (ordering food bags)

EWFAAO: Effect of the well-informed fraction of the adult population on the attractiveness of activity (ordering food bags)

Well-informed fraction effect on the attractiveness of activity reflects the effect of knowledge enhancement among the population on the attractiveness of ordering food bags in the platform and can be formulated as:

$$\mathrm{EWFAAO} = (1 - \mathrm{WFAPOP}) + \mathrm{WFAPOP} \times \mathrm{IEA} \qquad \text{Equation 37}$$

where:

IEA: Individual effect of education on the attractiveness of the app

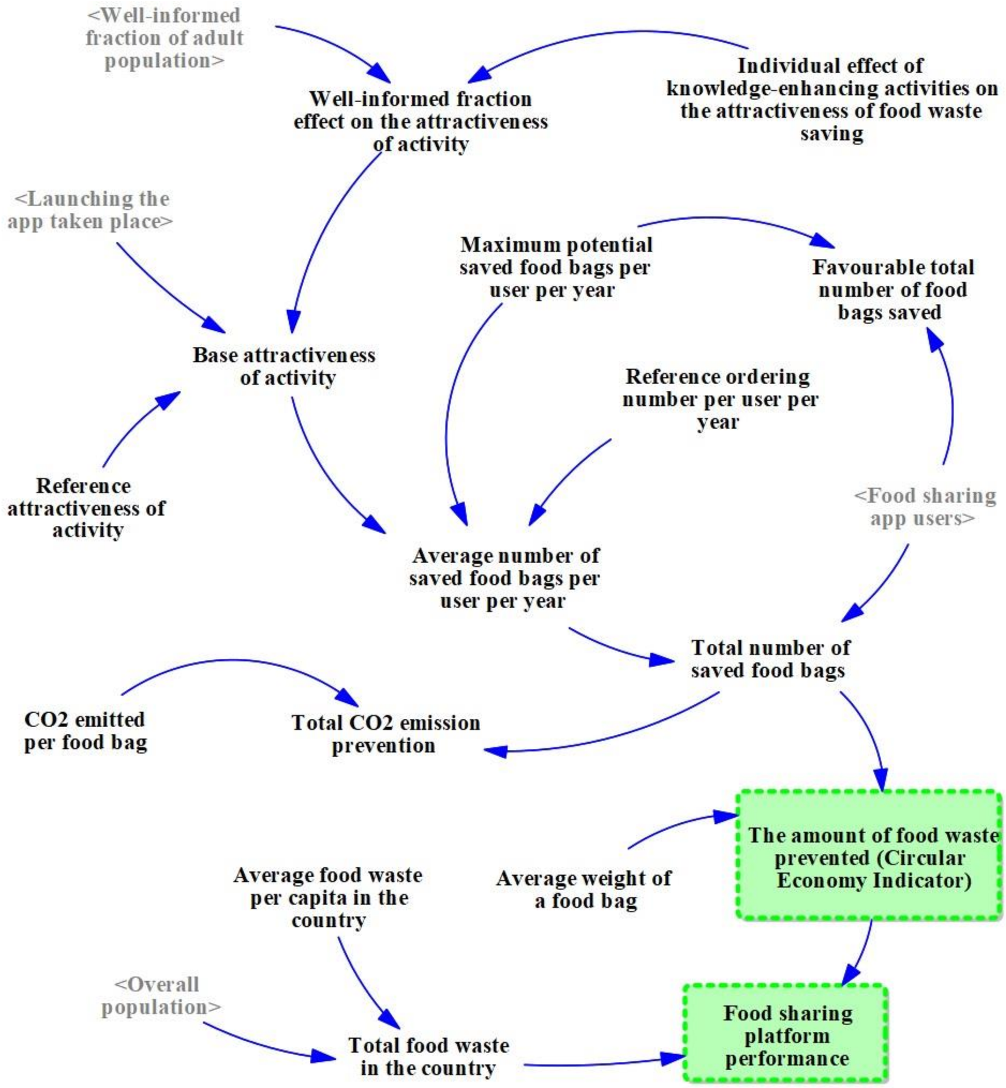


Figure 28. Causalities linked to the estimation of FW and CO_2 emission prevention and the circularity indicator.

In order to evaluate the effect of the diffusion and usage of the TGTG food sharing app and provide a clear and sensible picture, in the causalities shown in Figure 28, some causal relationships have been considered to estimate the total FW prevented, and its corresponding CO_2 emission prevented. In this regard, in line with the TGTG impact report of 2021 (TGTG, 2022c), the average weight of each food bag is assumed to be 1 kg, whose saving helps prevent 2.5 kg of CO_2e[§] that is almost equivalent to 5.75 kWh of electricity (considering European grid), sufficient to charge a smart phone 442 times.

To evaluate the contribution of the FSP to the CE over time, two indicators are defined and presented. First, the CE indicator, which refers to the amount of FW prevented through using the food sharing app. Second, the app's performance in terms of its contribution to the circular food system, which refers to the share of actual FW prevented through using the app to the whole FW generated at the national level. In this regard, the circularity indicator and TGTG performance are calculated based on the following equations:

$$\mathrm{CEI} = \mathrm{AWFB} \times \mathrm{TSFB} \qquad \text{Equation 38}$$

$$\mathrm{FSPP} = \frac{\mathrm{CEI}}{\mathrm{TFW}} \qquad \text{Equation 39}$$

where:

CEI: The CE indicator

AWFB: Average weight of each food bag

FSPP: FSP performance

TFW: Total FW in the country

The maximum potential saved food bags per person per year is assumed to be 12 in the model developed in the current thesis. Moreover, due to a lack of adequate data, assumptions have been made regarding the average number of saved food bags per person per year, which is an endogenous variable in the model. According

[§] CO_2 equivalent

to the website of TGTG (TGTG, 2022a), by the end of 2022, 6.9 million people used the TGTG app in Italy, and saved 10 million food bags. As the number of saved food bags is cumulative over approximately 4 years, the average number of saved food bags per person per year has been assumed to be 0.36 (i.e. $\frac{10\ million}{6.9\ million}/4$) in 2022 and the model is calibrated such that the simulated value corresponding to this variable approaches the estimated value. Table 20 presents the values used for exogenous variables in this section.

Table 20. Values used for the exogenous variables linked with the environmental assessment and the circularity indicator causalities.

Variable	Unit	Value	Reference/ Justification
Average FW per capita in the country	$kg/person*year$	31	The amount of FW per capita in Italy is estimated to be 595.3 gr per week (WWIO, 2022)
Maximum potential saved food bags per person per year	$bag/person*year$	12	Assumption
Individual effect of knowledge-enhancing activities on the attractiveness of FW saving	dmnl	2	Model calibration
Average weight of a food bag	kg/bag	1	(TGTG, 2022c)
CO_2 emitted per food bag	ton/bag	0.0025	(TGTG, 2022c)
Reference ordering number per user per year	$bag/person*year$	1	Assumption
Reference attractiveness of activity	dmnl	0.3	Assumption and model calibration

8.2. Model validation tests

Validation of a System Dynamics simulation model is a continuous process of building confidence in the model, which should be taken into account throughout the modeling process (Struben, 2006). In the validation process, both the structure and behavior of the model should be checked and their consistency with the existing knowledge about the system being studied should be shown (Homer, 2012). In this regard, several tests are suggested, including but not limited to boundary adequacy, dimensional consistency, structure assessment, behavior reproduction, sensitivity analysis, and extreme conditions (Struben, 2006).

The boundary adequacy was checked for the developed model by referring to the main designed structure in Figure 23 and the equations used in the model to make sure that the key concepts for addressing the research questions are endogenous to the model. Also, for the dimensional consistency test, the parameter units in the equations were inspected to assure their consistency and correspondence to the real world. Figure 29 presents the result of the unit checking test in Vensim software.

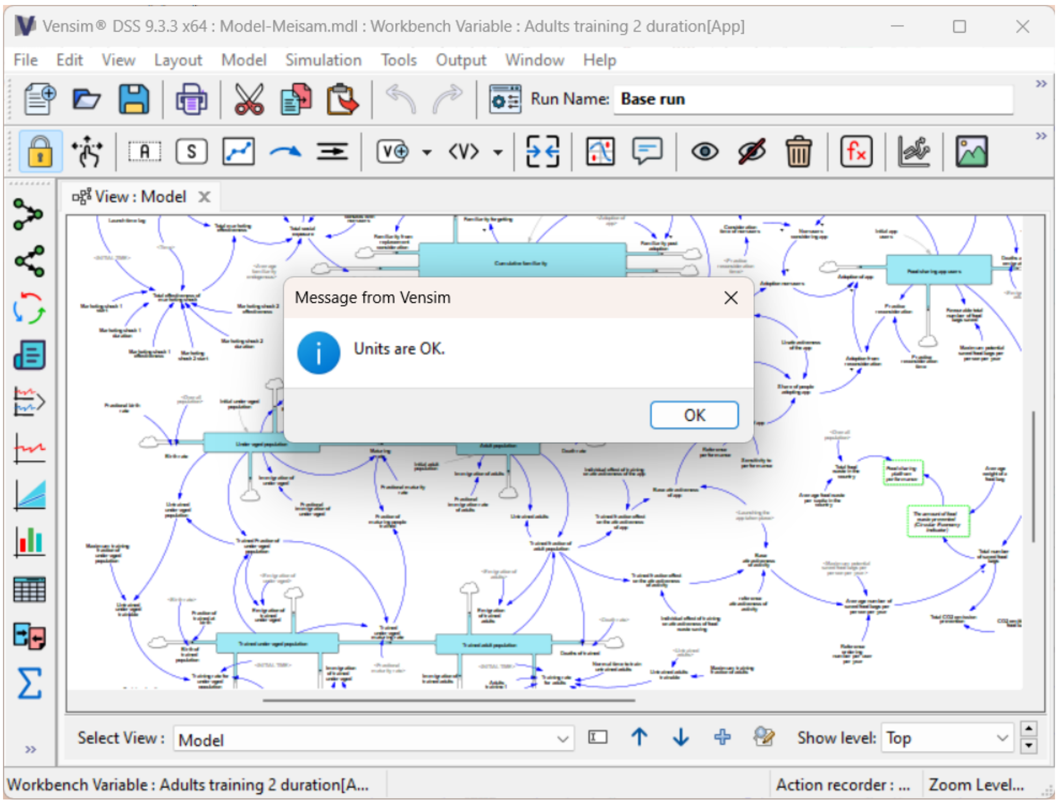


Figure 29. The result of dimensional unit testing.

In addition, partial model tests were conducted on different parts of the model to test its structure and behavior and evaluate the behavior of the entire model in reflecting the intended rationality of the decision rules (Struben, 2006). The simulated behavior of the key variables as well as results on testing their sensitivity are presented in the following sub-sections. In the base run of the simulation, values reported in section 8.1 are used for the parameters. Although the TGTG platform started its activities in Italy in 2019, the overall simulated period in this research is 2015-2060 to cover an adequate time span for reflecting the changes.

In line with the available data and the projections (ISTAT, 2022), the simulated flow of the population in Italy in Figure 30 follows a decreasing trend within the period 2015-2060. As stated in Section 8.1, the parameters are set in a way that the simulated values are logically close to the available trends; hence, the behavior of the population stock and flow structure can be relied on in the developed model.

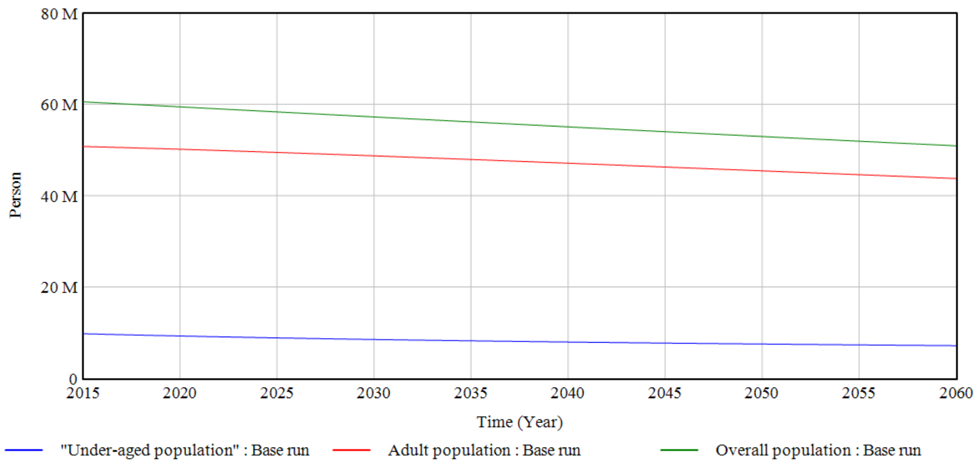


Figure 30. The simulated general dynamics of the population in Italy.

In order to test the rationality of the simulated behavior of the model, the response of the various parts of the model to different changes is tested. A part of the results of these tests is reported in this section. The main policies analyzed in this thesis are focused on marketing and knowledge-enhancing activities. Therefore, analyses of the model behavior in response to changes in the starting time, duration, and effectiveness of marketing and also knowledge-enhancing activities both for under-aged and adults are presented.

Figure 31 shows the dynamics in the cumulative familiarity of people and the number of app users in response to changes in marketing activities. In the scenarios presented in this figure, no knowledge-enhancing program is active in the model, but a slight regular marketing program is considered. Therefore, the dynamics in the behavior of cumulative familiarity are a result of changes in the marketing shock, which is an extra marketing effort such as a marketing campaign or strong social media and press promotions. Furthermore, testing different values for the starting time of the marketing activities shows that for a similar marketing starting time and effectiveness, the duration of the marketing makes very slight changes that can be negligible. This behavior is rational, as the attractiveness of the app is very high and joining the platform is easy, hence, familiarity with the app increases rapidly in the initial years and after that, the social contact among people and their word-of-mouth about the app keep the familiarity with this platform at a high level. Based on this analysis, for clarity in the visualization of the results, the effect of changes in the starting time and effectiveness of the marketing campaign on familiarity and the number of users is presented in Figure 31. Since the maximum value for marketing efforts based on the sensitivity tests is estimated to be 0.06, low and high marketing effectiveness considered in these scenarios are 0.01 and 0.05, respectively.

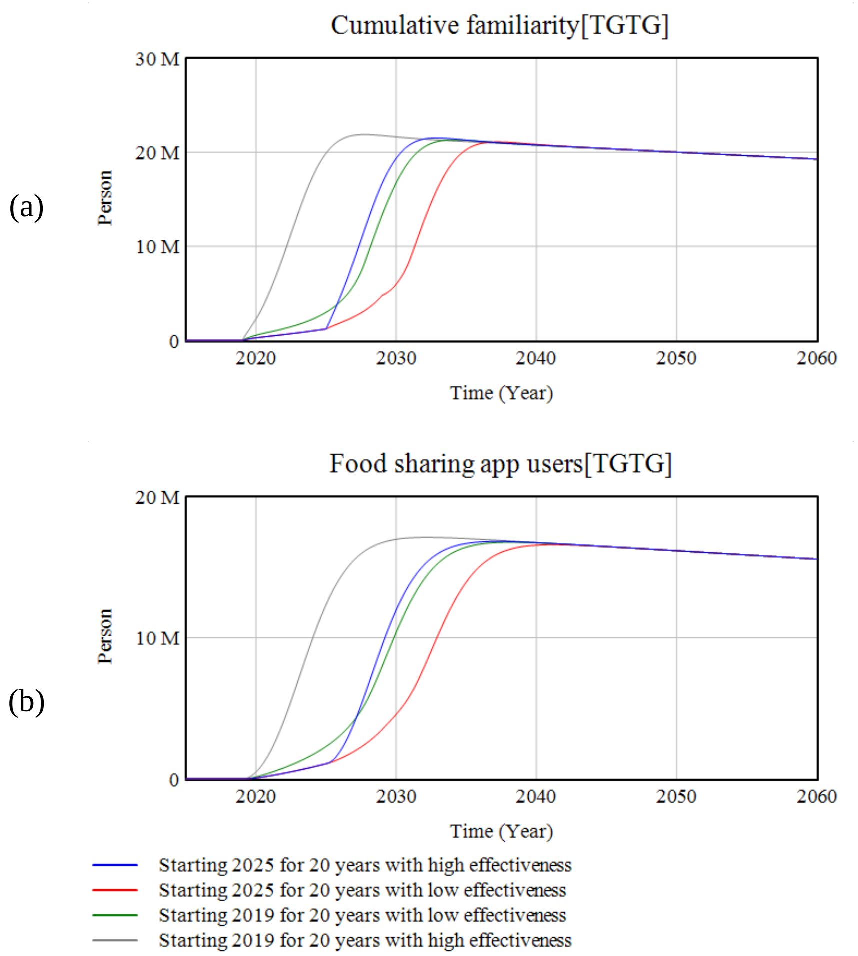


Figure 31. Dynamics of the cumulative familiarity (a) and number of app users (b) in response to changes in the starting time and effectiveness of marketing campaigns.

As can be seen in Figure 31, and as expected, more effective marketing plans increase familiarity in an earlier time, attracting more users. Besides, an earlier starting point for marketing campaigns results in a higher level of familiarity. The slight dent in the cumulative familiarity in the year 2029 refers to the end of the honeymoon period, during which marketing effectiveness is not endogenous. Comparing the dynamics in the cumulative familiarity and the number of users in this figure shows that although the trends observed in both variables are very close to each other, their scale is much different. While more than 20 million people are expected to be familiar with the app by 2050 based on the illustrated tested scenarios, around 16 million people are estimated to be users of the app. This is because a part of the eligible population, who are also familiar with the app, is not interested in using it due to various reasons.

Since marketing plans affect the familiarity of people with the app and is assumed not to affect their interest in increasing their number of food bag orders in the platform, the number of average food bag saved per user is not affected by changing marketing scenarios. On this basis, the amount of FW prevented (CE indicator) and the total CO_2 emission prevented, which are multiplications of the number of users with the average food bags saved per user and the CO_2 emission per food bag, respectively, follow the same dynamics as the users but with different scales. However, as shown in Figure 32, dynamics in the FSP performance are different with these indicators and the slope of its curves after 2040 does not decrease as much as the slope of the curve in the number of users. This is because the performance of the platform is set to be the fraction of total FW prevented by the app from the total FW generated in Italy. Hence, keeping the denominator constant, changes in the total amount of FW prevented, which is the CE indicator, change the performance of the app.

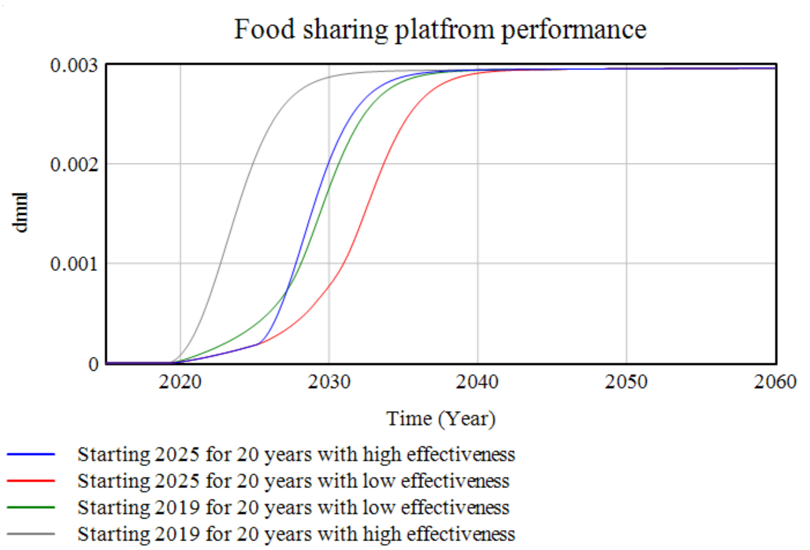
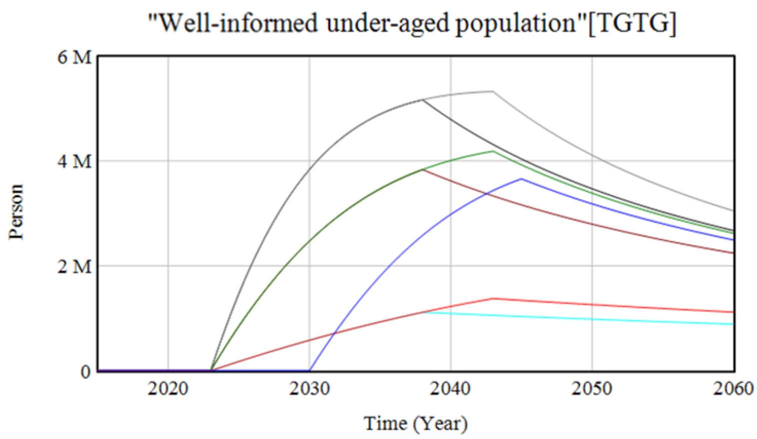


Figure 32. Dynamics in the FSP performance due to changes in the marketing plans.

In order to test the rationality of the behavior of the sub-system related to knowledge-enhancement in population and its effect on the dynamics of the overall system, changes in the knowledge-enhancing programs both for the under-aged population and for adults are analyzed. Figure 33 shows the dynamics in the number of well-informed children and the number of well-informed adults by considering knowledge-enhancing programs only for the under-aged population with different starting times, durations, and effectiveness. The low, average, and high effectiveness of knowledge-enhancing activities in these scenarios are considered 0.1, 0.5, and 0.9, respectively.

As expected, Figure 33(a) shows that earlier knowledge-enhancing programs, more effective programs, and longer-term activities result in a higher number of well-informed children. Also, in line with the findings of Shams Esfandabadi (Shams Esfandabadi, 2022), very effective knowledge-enhancing programs train a huge number of children in a relatively short period, and hence, the number of remaining educable under-aged population decreases in a short period, leading to decreases in the slope of the growing trend after a few years, as can be seen in Figure 33(a). Based on Figure 33(b), as the well-informed under-aged population mature and become adults, the number of well-informed adults starts to grow, following an s-shaped trend.

(a)



(b)

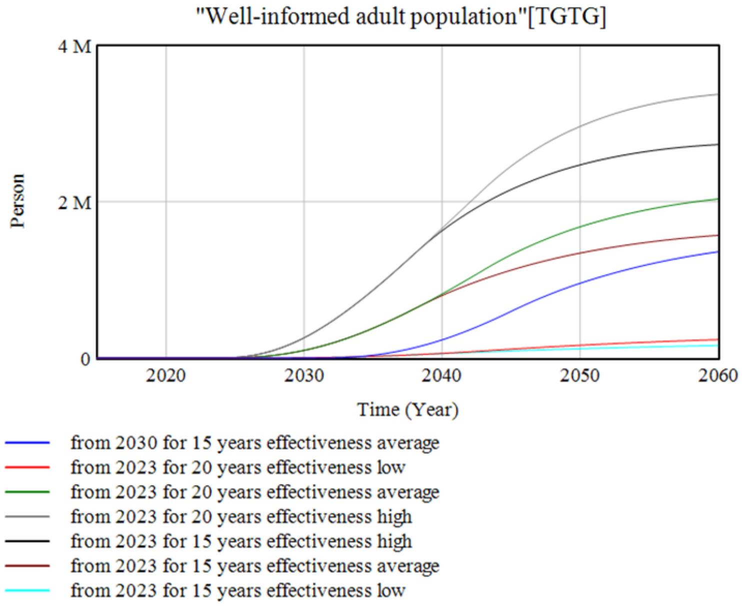
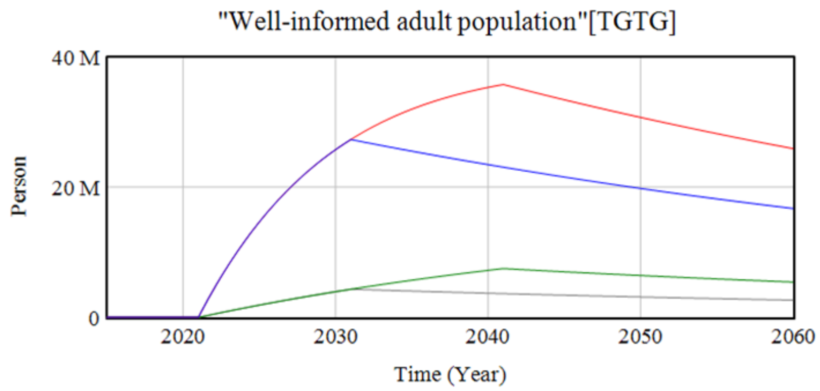


Figure 33. Dynamics of the well-informed under-aged population (a) and well-informed adult population (b) in response to changes in the starting time, duration, and effectiveness of knowledge-enhancing programs for the under-aged population.

Figure 34 presented the results of testing sample training scenarios for adults, assuming that no knowledge-enhancing activities have been previously considered for the under-aged population. To more clearly show the resulting dynamics, no marketing campaign is considered active while testing these scenarios, and the scenarios are tested with low and high effectiveness of knowledge-enhancing activities (i.e., 0.1 and 0.8, respectively). The starting point in all scenarios is set to 2021 for clarity in the visualization.

(a)



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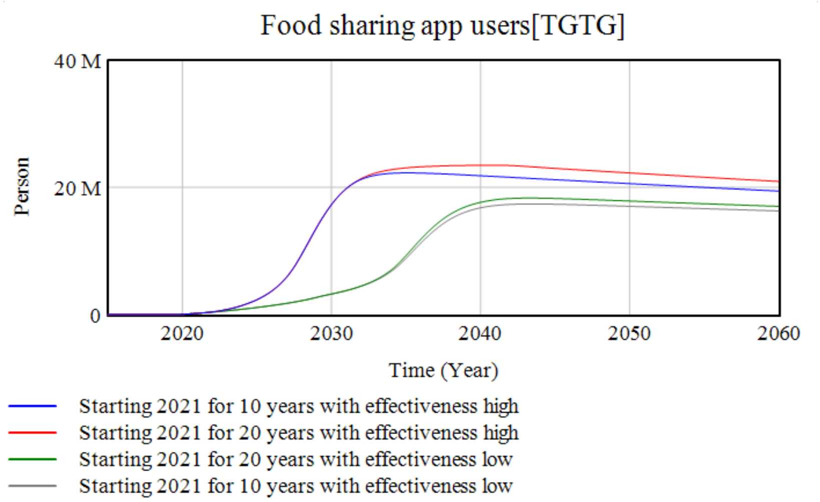


Figure 34. Dynamics of the well-informed adult population (a) and the number of app users (b) in response to changes in the duration and effectiveness of knowledge-enhancing programs for adults.

As can be seen in Figure 34(a), higher levels of effectiveness of knowledge-enhancing activities increase the number of well-informed adults at a higher rate. However, as a higher number of adults are well-informed, the rate of increase in the number of well-informed people reduces, due to the lower number of uninformed adults remaining. The growth of the number of well-informed adults affects cumulative familiarity, the attractiveness of joining the platform, and also the attractiveness of more effectively using the app by ordering more food bags. Therefore, changes in the familiarity and the attractiveness of using the app result in the dynamics illustrated in Figure 34(b). Moreover, an increase in the attractiveness of more effectively using the app over time leads to the dynamics in the average number of food bags ordered by each user per year, as illustrated in Figure 35. Since the knowledge-enhancing program is set to start in 2021, starting from this year, the average number of saved food bags by each person increases proportionally to the increase in the number of well-informed adults, raising the total number of food bags saved. This is followed by changes in the CE indicator, CO_2 emission prevented, and the platform performance, accordingly.

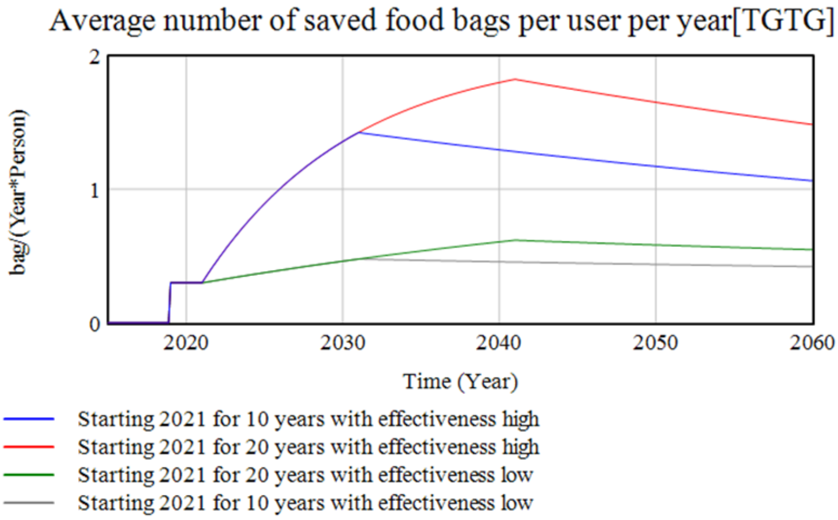


Figure 35. Dynamics of the annual average number of saved food bags per user in response to changes in the duration and effectiveness of knowledge-enhancing programs for adults.

The presented analyses in this section confirm the rational behavior of the system both in its different sub-systems and as a whole. In Chapter 9, the model is applied to run simulation scenarios to properly address the main research questions of the current thesis.

Chapter 9: Scenario Analysis and Policy Recommendation

In this chapter, first, the base run of the developed simulation model is presented and described (Section 9.1). Then, various relevant what-if scenarios regarding improving the current marketing efforts (Section 9.2), adding more efforts on knowledge-enhancing activities for adults (Section 9.3), and considering knowledge-enhancing programs for children (Section 9.4) are analyzed. Based on the insight gained from the analysis of what-if scenarios, in Section 9.5, a winning policy to improve the performance of the TGTG platform in Italy with regard to FW prevention is recommended and discussed.

9.1. Base run of the simulation

A stated in section 8.1.3, the model is calibrated such that the simulated number of users by the end of 2022 becomes close to 6.9 million people, the number reported in the website of TGTG in Italy at the end of 2022 (TGTG, 2022a) and the average number of food bags saved per user becomes close to 0.36 between 2019 and 2022. Since this app started its activities in Italy in 2019, a very sharp increase in the number of users is observed between the years 2019 and 2022. Evidence shows that very intensive social media and marketing support has led to such an increase in the number of users. Hence, in addition to the regular marketing programs that companies follow, a strong marketing campaign has been considered in the base run to simulate the current trend of the TGTG app users. Besides, while there is no report available on specific knowledge-enhancing activities for children regarding food sharing apps, based on the TGTG pact (TGTG, 2021), knowledge-enhancing activities for staff of the supermarkets, companies, and different points of sales are in place. Therefore, a knowledge-enhancing program for adults has been considered active in the base run. The developed base run of the simulation model provides estimations on the dynamics of the number of users in line with the data in available reports and also notes on the success of this app (Fragapane and Mortara, 2022).

The duration and effectiveness of marketing activities play a crucial role in ensuring the successful diffusion of products and technologies over time. These factors are influenced by various elements, including budget, target audience, market competition, product nature, and overall marketing strategy employed by the organization (Mela et al., 1997). In the base run of the model as shown in Figure 36, a 10-year extensive marketing campaign starting from 2019 with an effectiveness of 0.05 (which is rather high) has been considered. The starting time of this intensive marketing campaign is considered the same time as starting the activities of TGTG to Italy. Considering that no exact duration can be estimated for such a strong marketing campaign, to analyze the effect of this marketing shock, it is assumed that this marketing campaign last for 10 years (i.e., until 2029). Besides, a 15-year period of knowledge-enhancing activities for adult population starting from 2021 in line with the "pact against food waste" initiative launched by TGTG (TGTG, 2021), with an effectiveness of 0.2 (which is rather low) has been considered in the base line. Although the period of the knowledge-enhancing program is not stated in any report, the knowledge-enhancement period is limited to 15 years to better analyze the dynamics of the system. It should be noted that based on the sensitivity analysis, the maximum marketing effectiveness can be 0.06 and the maximum effectiveness of knowledge-enhancement can be 1.

Figure 36 shows the base run, base run ignoring knowledge-enhancing activities, and also base run ignoring the marketing campaign to highlight the role these forces have in the number of app users. Focusing on the green line, which represents the base run simulation, it can be clearly seen that TGTG in Italy is expected to follow an s-shaped curve and become sustained after around 2040. This is a sign of success for this platform, which is confirmed in other research and media (Fragapane and Mortara, 2022). This can be due to several reasons, including the attractiveness of app (as it provides opportunities to buy surprise boxes of food with a lower price than usual and without registration fees) and also the ease of becoming a member (as app is a different type of product in comparison with tangible and durable products and technologies). The decreasing trend after the market has become sustained can be linked to the decreasing trend of the population in Italy. However, in the following sections, potential scenarios to increase the number of TGTG food sharing app users in Italy are discussed.

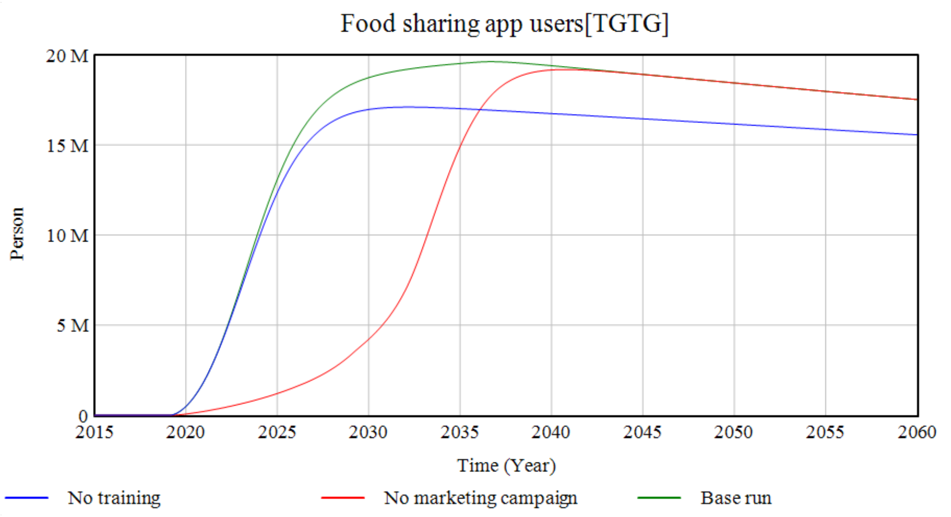


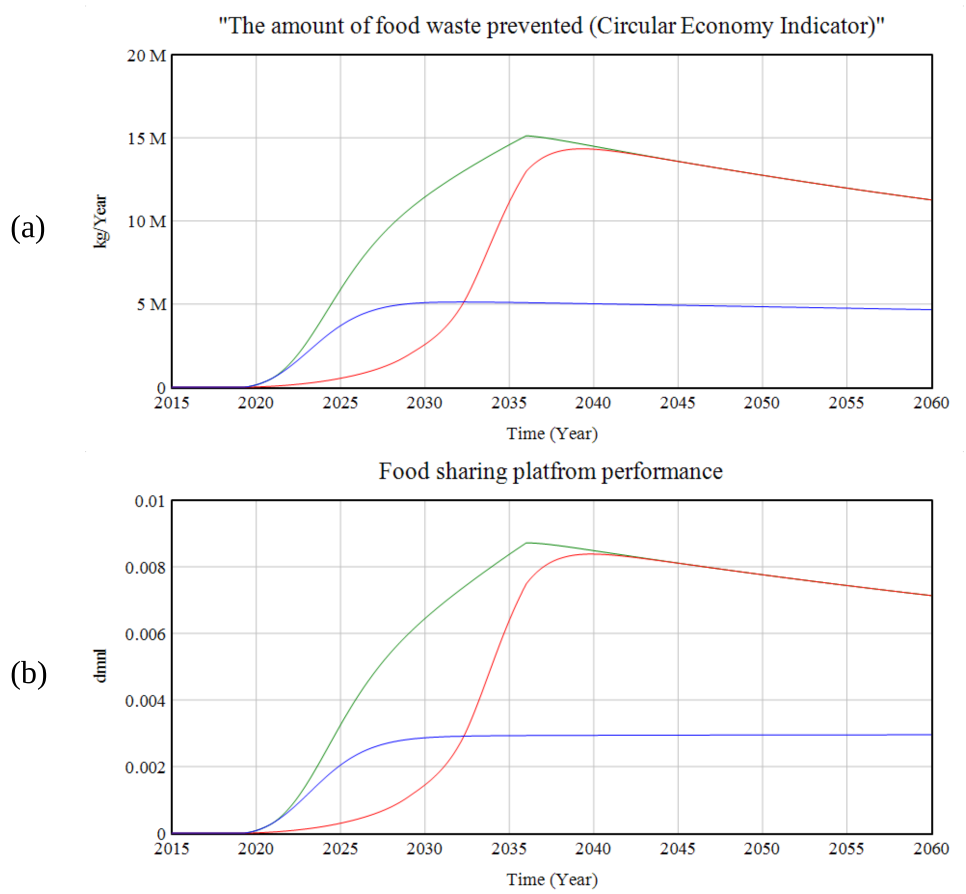
Figure 36. The specific roles of marketing campaign and knowledge-enhancing activities on the number of TGTG users in the base run.

In Figure 36, in the "no marketing campaign" scenario, the intensive marketing campaign has been removed from the base run. However, a slight marketing activity, as a regular activity of a company is still taking place. The difference between the trend of base run and the no campaign scenario until 2045 highlights the key role of marketing campaign in the sharp growth of the number of TGTG app users in a short period. Without such a strong media and marketing efforts, the growth of the number of users would be due to the slight marketing activities, slight knowledge-enhancing activities considered in the base run based on the pact, and also due to social exposure among people and word-of-mouth among them.

In the “no knowledge-enhancement” scenario, the key role knowledge-enhancement plays in the number of users is highlighted. While marketing forces the initial take off of the number of users and gives it a sharp slope, knowledge-enhancement keeps the attracted users in the system.

In addition to the role of intensive marketing and knowledge-enhancement in the number of users, these main activities affect other parts of the system, that are considered for assessing the impacts of the food sharing app. Figure 37 shows the dynamics in the amount of FW prevented (the CE indicator), the platform performance, and the CO_2 emission prevented. These indicators have similar trends with different scales. Comparing the trends referring to the base line, no marketing campaign, and no knowledge-enhancement shows that the role of knowledge-enhancing programs in the improvement of these indicators is higher than marketing. This is while marketing played a more critical role in increasing the number of users, especially in the initial stages of the activity of the app. The main reason could be the fact that all members of the app are not necessarily its active users. A simple comparison between the total number of users at the end of 2022 (6.9 million) with the total food bags saved since 2019 (10 million) (TGTG, 2022a) shows that a huge number of users are not using the app. Furthermore, when people are well-informed about the FSPs and related subjects such as the best time to consume and the expiry date of the food products, not only they become interested in joining the app, but also, they are more motivated to use the app by ordering food bags. More food bag ordering per user in the platform increases the amount of FW prevented, which consequently improves the performance of the app, and also prevents a higher amount of CO_2 emission.

Comparing the values and scales in Figure 36 and Figure 37 highlights the fact that although the number of TGTG users are growing very fast and the app is introduced as a successful app in the market, the environmental and CE indicators can and must improve significantly. Therefore, in the following sub-sections potential scenarios to improve the indicators, as well as the number of users, are analyzed and discussed. Finally, the best potential scenario is recommended at the end of this chapter.



(c)

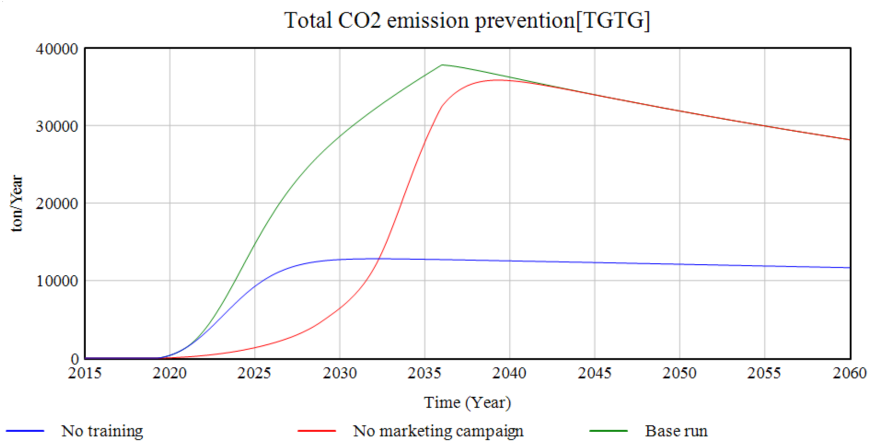


Figure 37. The specific roles of marketing campaign and knowledge-enhancing activities on the CE indicator (a), TGTG performance (b), and total CO_2 emission prevention (c), in the base run.

9.2. Bolstering marketing campaigns

To test the effect of marketing efforts on the number of TGTG users, the performance of TGTG, and the amount of FW prevented (i.e., the CE), three different potential future scenarios are considered. To this end, an additional marketing shock according to the described criteria in Table 21 are added the already active marketing and knowledge-enhancing activities in the base run. Due to the importance of duration, starting point, and effectiveness of the marketing highlighted by Shams Esfandabadi (2022) and Struben (2006) and also shown in Section 8.2, different starting times and durations are tested. In this regard, the effectiveness of the additional marketing campaign is set to maximum.

Table 21. Potential scenarios tested regarding extra marketing activities (in addition to the current marketing campaign).

Scenario	Starting time	Duration (year)	Effectiveness
M1	2023	10	0.06
M2	2023	30	0.06
M3	2030	20	0.06

As illustrated in Figure 38, while the marketing scenarios M1 (starting from 2023 and keeping it for 10 years) and M2 (starting from 2023 and keeping it for 30 years) are very close to each other, the marketing scenario M3 (starting from 2030 and keep it for 20 years) and the base run are close to each other. According to the simulation results, starting marketing efforts late (2030) does not considerably change the dynamics of the number of users in comparison with the base run. While initiating the additional campaign earlier may have a minimal impact, the duration of the campaign does not significantly influence the outcome as the market is already saturated. Besides, although after around 2036, a slight decrease in the trend is seen, which is because of the end of the knowledge-enhancing program assumed in the base run, the market is considered a successful market in terms of the number of users as it is expected to follow an s-shaped curve and become sustained after around 2040. The simulated number of users in 2060 based on the base run is approximately 17,524,100 people. In this regard, a successful s-shaped growth in the market that lasts for a long period is clearly seen in Figure 38.

This shows that the TGTG marketing campaign is already performing very effectively. This can be confirmed by the available data regarding the significantly increasing number of TGTG users over its few years of activities in Italy. From March 2019 (TGTG starting time in Italy) to the end of 2022, the number of TGTG users has reached 6.9 million in Italy (TGTG, 2022a), which is a significant growth. This is also in line with the research conducted by Fragapane and Mortara (2022) introducing TGTG in Italy as a successful food sharing app that has a large presence in Italy. Moreover, during its short period of activity in Italy (less than four years), TGTG has managed to reach over 45,000 partners, such as Carrefour, EATALY, naturasi, coop Centro Italia, GROM, and Venchi 1878.

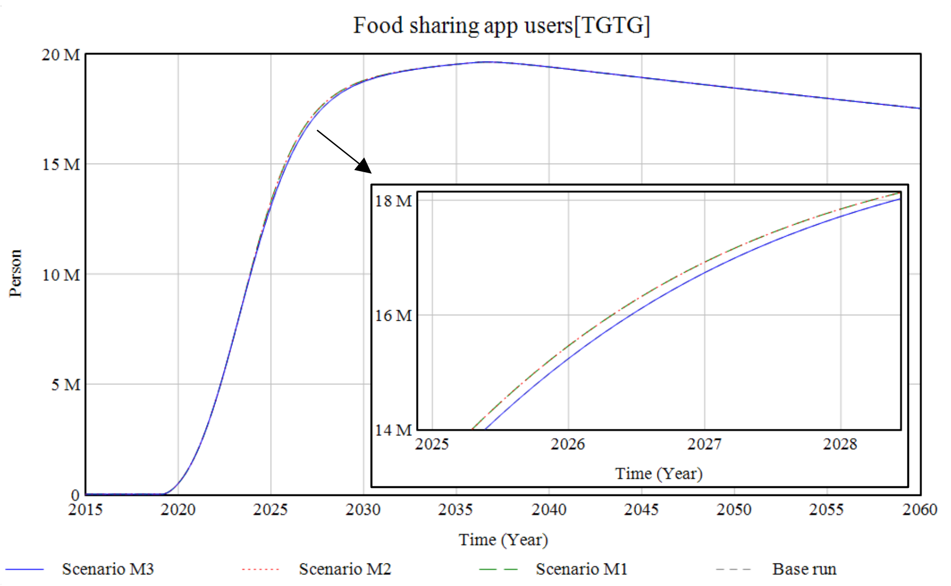


Figure 38. The effect of extra marketing shock scenarios on the number of TGTG users.

Based on the high number of users and also the rapidly increasing trend of new users, TGTG has a very effective marketing campaign. For instance, according to the website of TGTG in Italy, while the number of users was 6.9 million by December 10, 2022 (the access date to the website), this number increased to 7 million users on January 13, 2023 (TGTG, 2022a). This shows 100,000 newly joined users in around one month, which is very notable and highlights the TGTG app as a successful initiative in terms of the number of users.

In this regard, there might be several potential reasons for such a fast growth in the number of TGTG app users. First, it is very easy to join and use the app. Unlike many other technologies and products, potential new users can easily access the app and install it on any device for free. Second, TGTG's social exposure seems to be high and effective. The current marketing efforts of TGTG have led to increasing social exposure for potential users. As explained in Chapter 8, the reinforcing loop shown in Figure 23 and Figure 26 indicates this positive effect. In this vein, marketing increases total social exposure, then, social exposure leads to familiarity increase, and accordingly, when familiarity goes up, word-of-mouth among people regarding the TGTG app rises. Therefore, effective contact between people leads to an increase in total social exposure again, creating a positive loop within the system. Based on the developed model, this loop is working properly and shows the significant role of effective marketing in increasing the number of TGTG users. TGTG has a large existence in social media, news, the press, and social events. For instance, TIME introduced TGTG as one of the times 100 influential companies in 2022, and Vo-Thanh et al. (2021) identified TGTG as the largest social movement in Europe dedicated to fighting FW. Moreover, the TGTG app ranked 10th among the most downloaded apps in the food and beverage industry in the world, highlighting the significant attention gained by this FSP (TGTG, 2022c).

As shown in Figure 39 and Figure 40, applying extra marketing efforts as in scenarios M1, M2, and M3 marketing scenarios does not have significant impact on TGTG performance and the CE indicator, since the changes are very tiny. The main reason for this tiny change is that marketing affects the attractiveness of joining the app, and hence, does not increase the average number of food bags saved by each user significantly. On this basis, since extra marketing efforts (in addition to what already exists in the base run) do not make considerable changes in the number of TGTG users, they cannot significantly affect the amount of FW prevented (i.e., the CE indicator) and the performance of the platform (the share of the FW prevented from the whole FW generated in the country). As can be seen from Figure 39 and Figure 40, while the dynamics of both FSP performance and the CE indicator in M1 and M2 scenarios are very close, M3 is close to the base run.

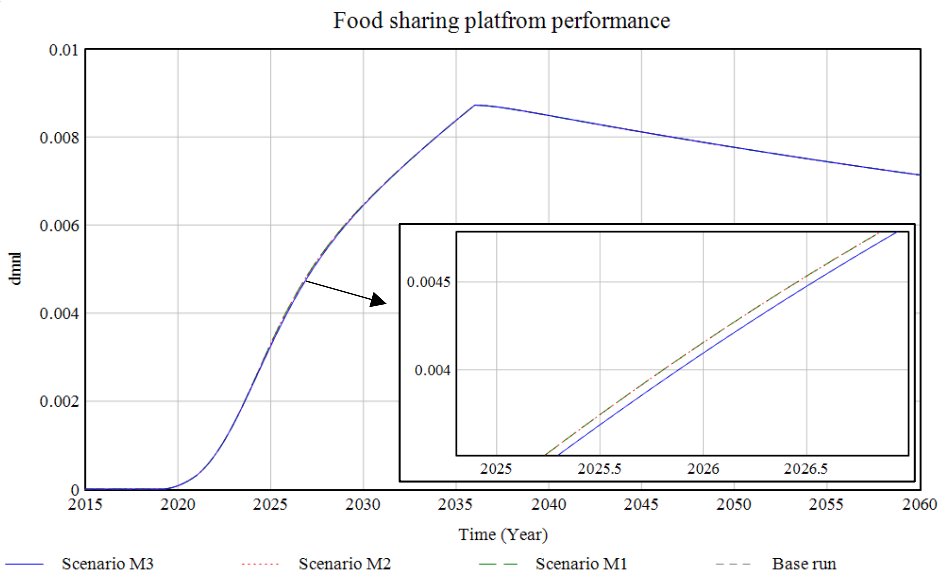


Figure 39. The effect of extra marketing shock scenarios on TGTG performance.

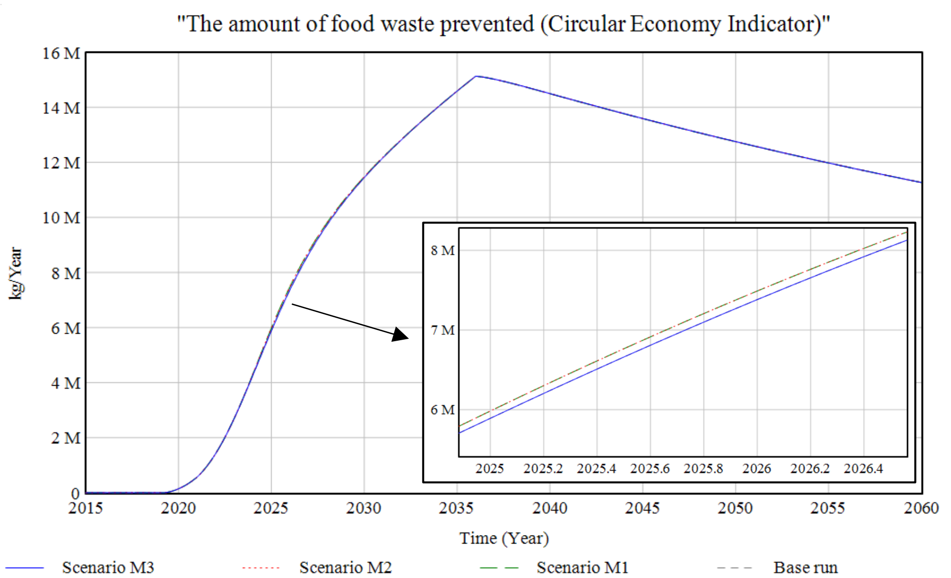


Figure 40. The effect of extra marketing shock scenarios on the number of TGTG users.

In conclusion, the current marketing effectiveness of TGTG in the base run is adequately high and putting extra effort into marketing activities does not make a significant change in the number of users, the platform performance, and the CE indicator. Hence, keeping the current marketing profile of TGTG seems to be sufficient for its success in terms of the number of users but further attempt should be made via other means to improve the CE indicator and leverage the platform performance in fighting against FW in Italy.

9.3. Knowledge-enhancing programs for adults

A comparison between the total number of users at the end of 2022 (6.9 million) with the total food bags saved since 2019 (10 million) (TGTG, 2022a) shows that a huge number of users are not using the app. According to Pisoni et al. (2022), a survey conducted on TGTG users revealed that a significant proportion of individuals who have signed up for TGTG do not follow through with making a purchase. However, when people are educated about the FSPs and related subjects such as the best time to consume and the expiry date of the food products, not only do they become interested in joining the app, but also, they are more motivated to use the app by ordering food bags. More food bag ordering per user in the platform increases the amount of FW prevented, which consequently improves the performance of the app, and also prevents a higher amount of CO_2 emission.

In order to analyze the effect of knowledge enhancement among adult population on the behavior of the key variables and indicators in the model, the potential changes in the knowledge-enhancing activities have been analyzed in three categories of scenarios.

First, what if the currently active knowledge-enhancing activities for adults (based on the TGTG's pact) continue for an extended period? In the base run, the duration of these knowledge-enhancing activities has been assumed to be 15 years. Hence, the potential dynamics resulting from continuing these knowledge-enhancing activities with the same effectiveness for longer periods are compared with the base run. Second, what if the current knowledge-enhancing effort is kept as assumed in the base run (from 2021 to 2036), but an extra knowledge enhancing effort is added to it as soon as possible (starting from 2023)? Third, what if the current knowledge-enhancing efforts are kept for an extended period (for 30 or 40 years instead of 15 years) and extra knowledge-enhancing efforts are added to it as soon as possible (starting from 2023)?

9.3.1. Keeping the current knowledge-enhancing activities for adults for an extended period

In this set of scenarios, the existing knowledge-enhancing activities already included in the "pact against food waste" initiative launched by TGTG in 2021 are kept unchanged over an extended period of 30 and 40 years, instead of 15 years. The dynamics in the key variables in these scenarios in comparison with the base run are illustrated in this section. As stated in section 9.1, in the base run, knowledge-enhancing activities have been included in the TGTG's pact since 2021, with an effectiveness of 0.2, and it is assumed that these activities are kept in place for 15 years.

Continuing knowledge-enhancing programs for adults leads to an increase in the number of the well-informed adult population. Therefore, with the increase in the well-informed adult population, the number of food sharing app users goes up. As shown in Figure 41(a), in the base run, the number of users starts to decrease from 2038. In this regard, continuing the current knowledge-enhancing effort for 30 years (scenario KA1) increases the number of users until 2051 but decreases it from 2051 onwards. This is while keeping the current activities for 40 years (scenario KA2) can sustain the market. The slight decrease near 2060 is due to the decrease in population in Italy based on the available projections regarding the population of Italy (ISTAT, 2022).

(a)

(b)

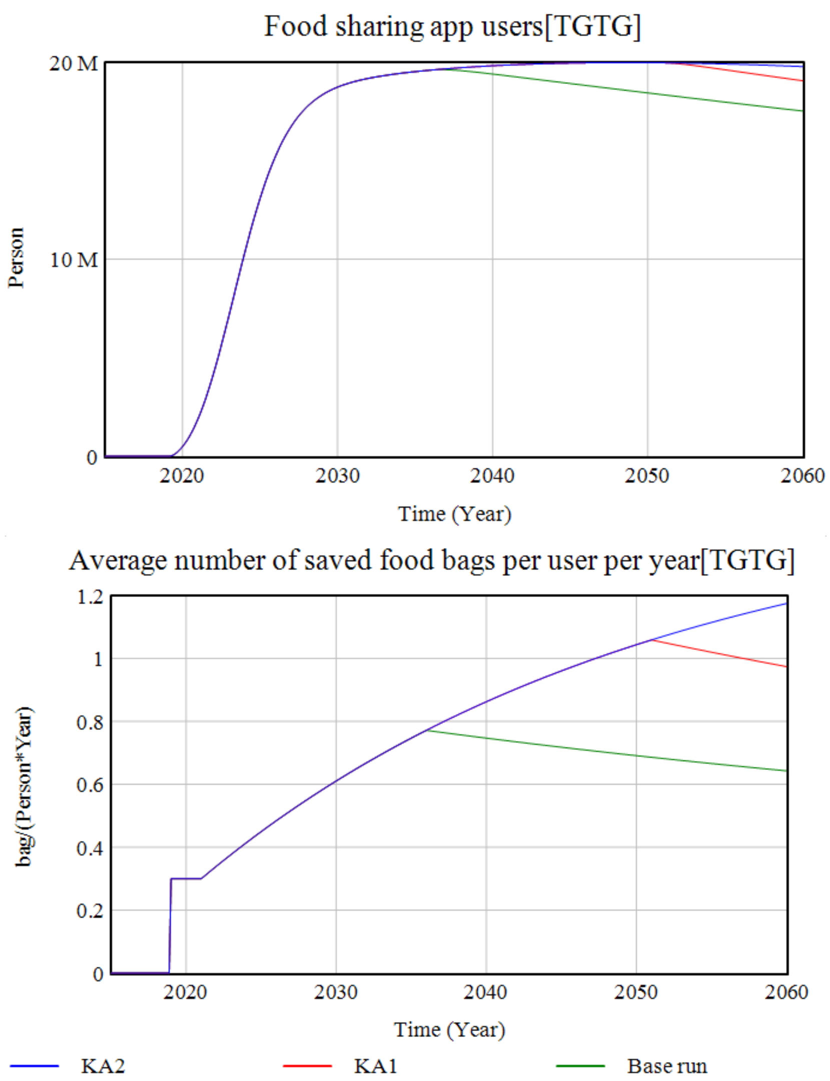


Figure 41. The effect of keeping the current knowledge-enhancing activities for adults for a long time on the number of TGTG users (a) and the average number of saved food bags per person per year.

The base run shows that the average number of saved food bags per person per year is 0.36 of a food bag in 2022. According to the model, knowledge-enhancing activities and plans positively affect the attractiveness of using the food sharing app to make orders and accordingly save more food products. Hence, as shown in Figure 41(b), knowledge-enhancing programs have a significant impact on the number of saved food bags. For instance, the base run, which includes a 15-year knowledge-enhancement plan starting from 2021, shows a continuously increasing trend in the average saved food per person. However, once the knowledge-enhancing activities stops in 2036, the average saved food per person starts decreasing. In this vein, 30 years of knowledge-enhancing activities for adults lead to a continuous increase in the average saved food by 2051, reaching an average number of 1.059 saved food bags per person per year. According to Figure 41(b), continuing the current knowledge-enhancing activities constantly increases the average number of annual saved food bags per person by 2060, reaching around 1.2 bags per person, which is a significant improvement compared to the base run.

Implementing each of the described scenarios shows a positive outcome in terms of the contribution to the CE through the amount of FW prevented in TGTG. As illustrated in Figure 42(a), scenario KA2 can be more effective in terms of the amount of FW prevented. In this regard, the amount of FW prevented increases constantly by 2060, reaching 23,246,200 kg. This is while the base run scenario will lead to a decrease in the amount of FW prevented from 2036 to 2060 due to the lower level of knowledge-enhancing activities compared to the longer-term knowledge-enhancing efforts. Besides, since the average weight of each food bag in TGTG is assumed 1 kg, whose saving helps prevent 2.5 kg of CO_2e (TGTG, 2022c), this scenario results in similar dynamics in CO_2 emission prevention but in a different scale, as shown in Figure 42(b). On this basis, scenario KA2 results in a continuous reduction of CO_2 emissions by 2060, reaching more than 58,000 tons of CO_2 emission prevented per year in 2060. Hence, long-term knowledge-enhancing plans significantly influence food resource efficiency and the environment towards a CE transition in the food sector. Accordingly, since the amount of FW prevented is increased by continuing the knowledge-enhancing activities, the performance of the app improves continuously, as shown in Figure 42(c).

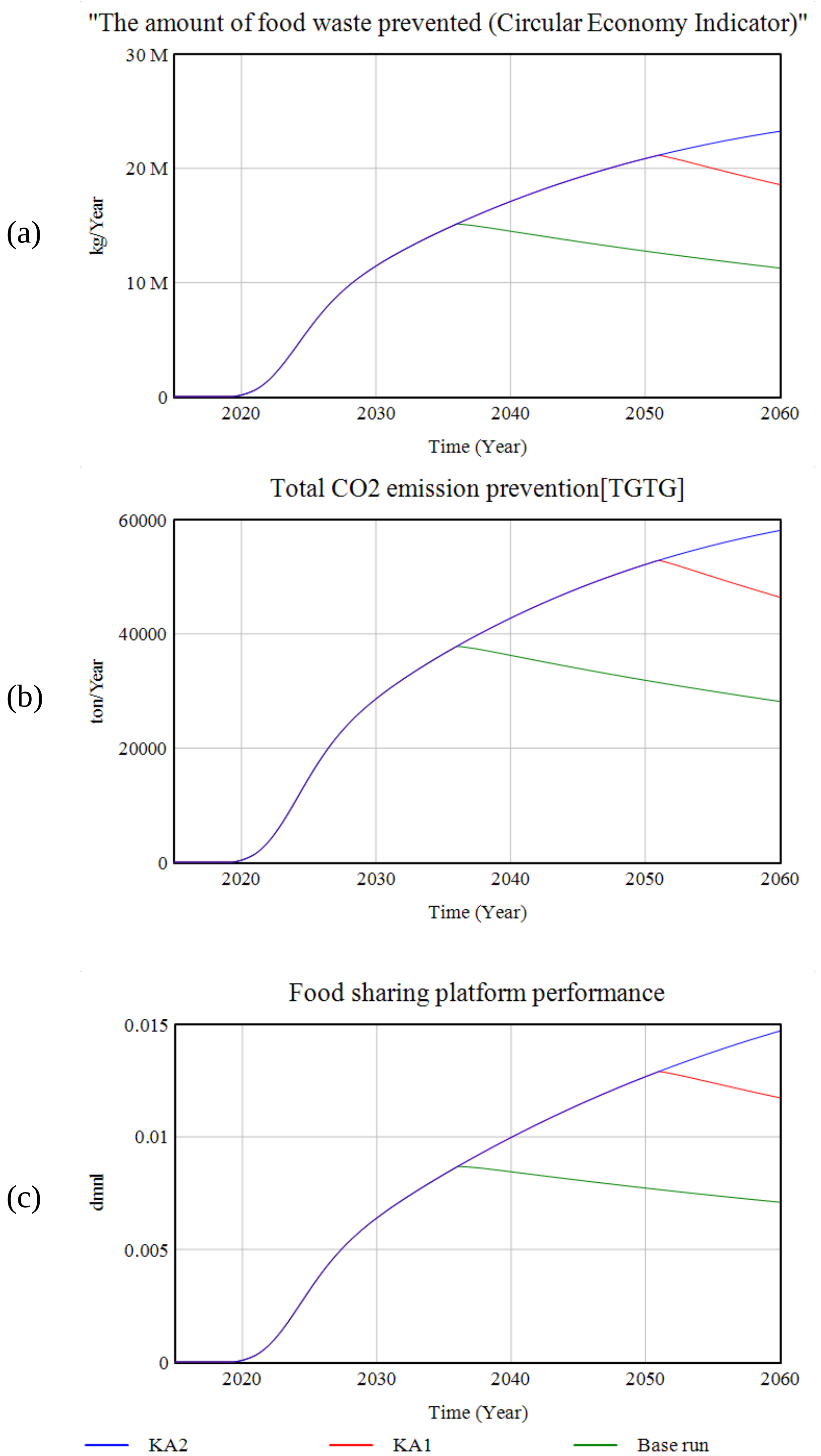


Figure 42. The effect of keeping the current knowledge-enhancing activities for adults for a long time on the amount of FW prevented (the CE indicator) (a), the total CO_2 emission prevention (b), and TGTG performance (c).

9.3.2. Adding extra efforts to the current knowledge-enhancing activities

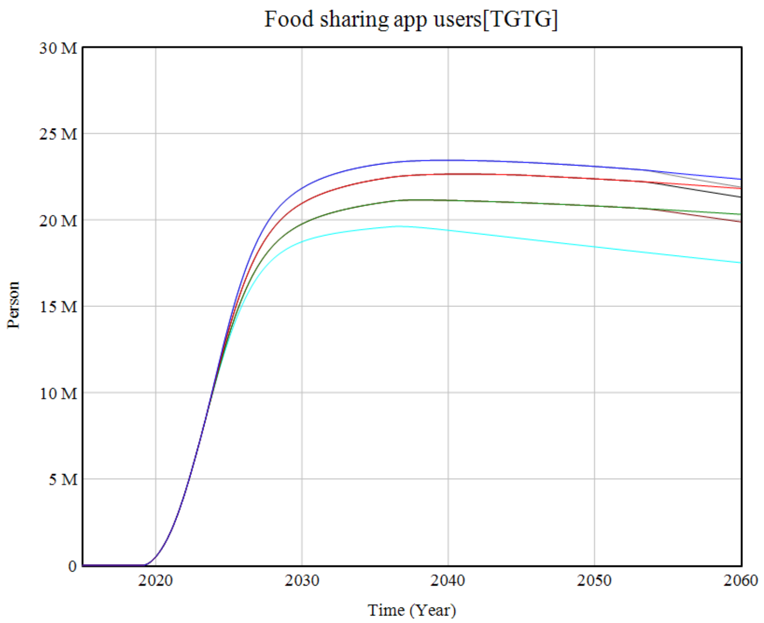
The scenarios introduced in Table 22 maintain the current knowledge-enhancing effort in the base run while incorporating additional knowledge-enhancing efforts of varying durations. All scenarios start from 2023 as the analysis presented in section 8.2 showed that the earlier knowledge-enhancing activities start, the higher the number of well-informed people over time would be, hence, the system can be more successful. Three levels of knowledge-enhancement effectiveness, including 0.2, 0.5, and 0.8, are considered to test different scenarios. In scenarios KA3 and KA6, the effectiveness of the extra knowledge-enhancing programs is equal to the effectiveness of the currently active knowledge-enhancing efforts in the base run (0.2).

Table 22. Scenarios regarding adding extra knowledge-enhancing efforts for adults to the base run.

Scenario	Starting time	Duration (year)	Effectiveness
KA3	2023	30	0.2
KA4	2023	30	0.5
KA5	2023	30	0.8
KA6	2023	40	0.2
KA7	2023	40	0.5
KA8	2023	40	0.8

While increasing the duration of already active knowledge-enhancing activities leads to continuing almost the same trend for the number of users (as shown in Section 9.3.1), adding extra knowledge-enhancing programs to the current attempts, as shown in Figure 43(a), changes the slope of the lines in comparison with the base run. Moreover, the greater the effectiveness of knowledge-enhancing activities, the steeper the slope of the lines representing the dynamics of well-informed individuals and food sharing app users. Starting from 2036, when the current knowledge-enhancing program (in the base run) ends, a slight decrease in the number of users is observed. Comparing the dynamics resulting from each pair of scenarios with similar knowledge-enhancing effects (KA3 and KA6, KA4 and KA7, KA5 and KA8) shows that keeping the extra knowledge-enhancing programs for a longer period is more effective in keeping the number of users as high as possible. In any case, adding extra knowledge-enhancing activities to the current situation can increase the number of users in comparison with the base run. Furthermore, the average number of saved food bags per person is affected by knowledge-enhancement, hence, increases accordingly. From 2019 to 2021, the average number of food bags saved per person is assumed constant. By starting knowledge-enhancing efforts in 2021 based on the TGTG's pact, there is an increase in the average number of food bags saved per user. If extra knowledge-enhancing efforts are put into force for adults starting from 2023, a sharper increase in the number of average bags saved per user will be achieved, as shown in Figure 43(b), which is very favorable. Hence, as the additional knowledge-enhancing efforts increase in both intensity and duration, the average number of food bags saved per user also goes up.

(a)



(b)

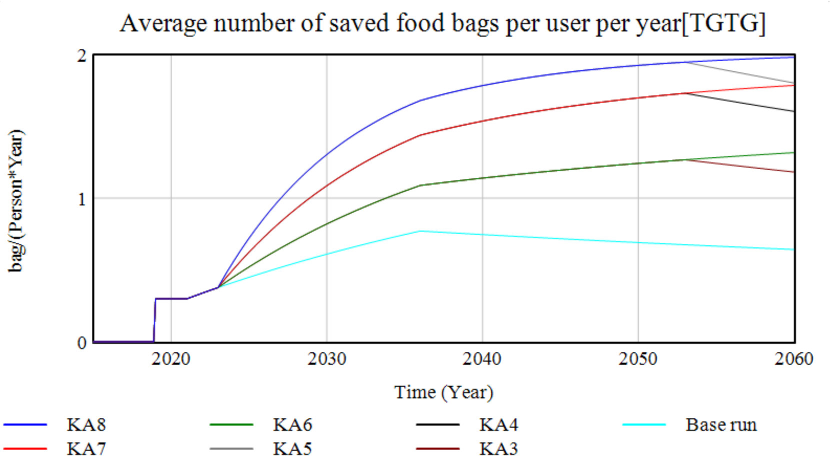
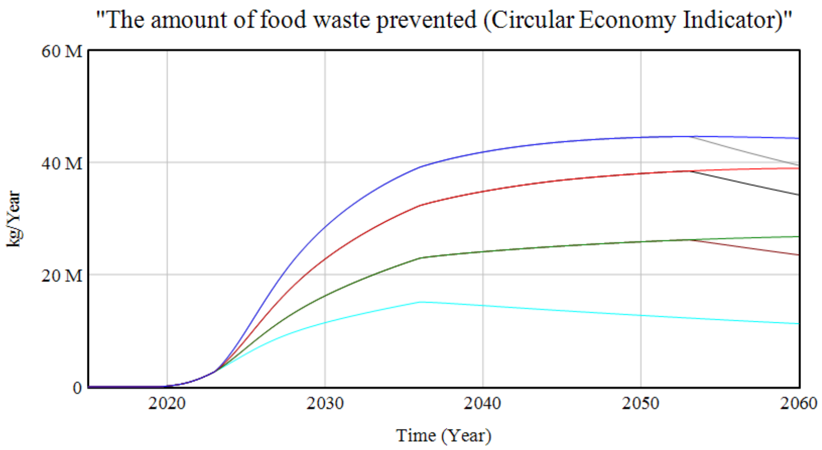


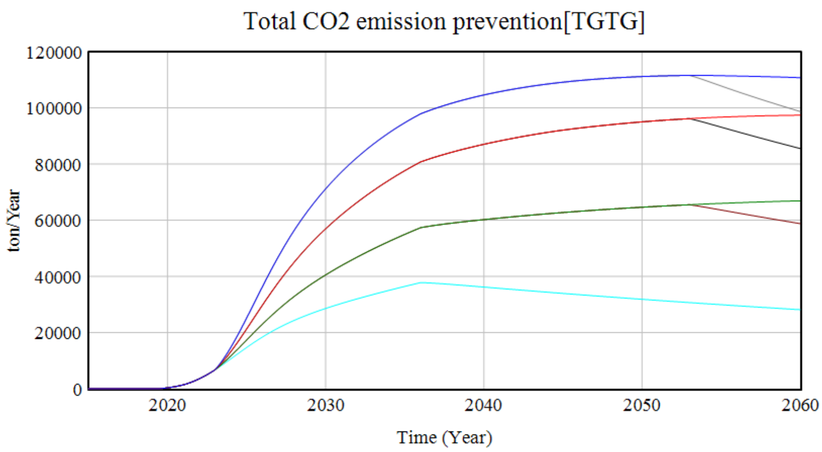
Figure 43. The effect of adding extra knowledge-enhancing efforts for adults to the base run on the number of TGTG users (a) and the average number of saved food bags per person per year (b).

As can be seen from Figure 44(a), increasing knowledge-enhancing activities for adults makes significant changes in the total amount of FW prevented compared to the knowledge-enhancing activities in the base run. In this regard, while the amount of FW prevented starts to decrease in 2036 (ending time of knowledge-enhancing activities in the base run), a lengthier knowledge-enhancing program and a higher level of effectiveness in knowledge enhancement activities lead to a higher amount of FW prevented. Scenario KA8 with a duration of 40 years and effectiveness of 0.8 leads to the highest FW prevention by TGTG, reaching 44,313,200 kg of annual prevented FW in the year 2060. This is while the base run scenario reaches 11,272,400 kg of FW prevention in 2060, which is almost four times smaller than the amount prevented by scenario KA8. The significant difference between scenario KA8 with the base run scenario regarding FW prevention denotes the critical role of additional knowledge-enhancing programs and plans to foster the CE transition and FW prevention. Accordingly, the total CO_2 emission prevention shows approximately similar dynamics in a different scale, as shown in Figure 44(b). Although the dynamics in the FSP performance shown in Figure 44(c) seems to have a similar dynamics as the CO_2 emission prevention and the CE indicator, the slope of the curve at different points of time for this indicator is different with the other two indicators. As highlighted in Section 8.2, the main reason for this difference is that the platform performance reflects the share of FW prevented by the platform from the total FW in Italy, while the CE indicator and the CO_2 emission prevention are a multiplication of the total number of food bags saved.

(a)



(b)



(c)

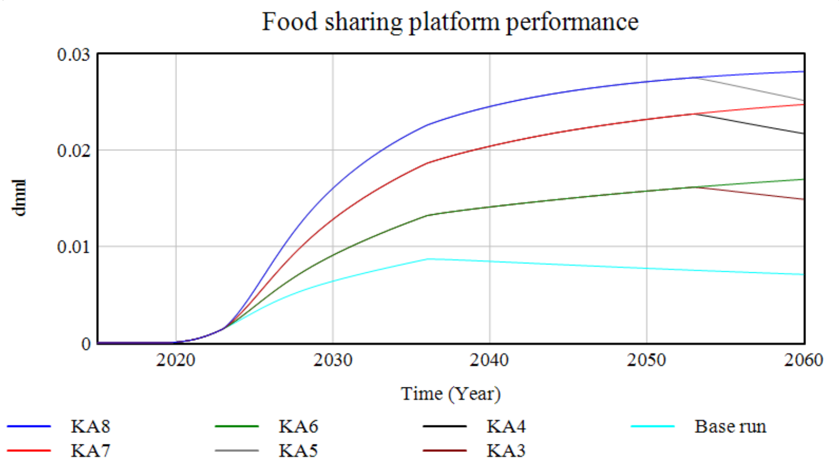


Figure 44. The effect of adding extra knowledge-enhancing efforts for adults to the base run on the amount of FW prevented (the CE indicator) (a), the total CO_2 emission prevention (b), and TGTG performance (c).

9.3.3. Extensive knowledge-enhancing programs for adults

Analyses presented in Section 9.3.1 regarding training and informing adults showed that keeping the currently active knowledge-enhancing efforts for 40 years is more rewarding than ending them in a shorter period of time. Besides, analysis in Section 9.3.2 highlighted that putting additional knowledge-enhancing efforts, other than the currently active knowledge-enhancing programs, into practice can leverage both the number of users and the environmental indicators. In the scenarios analyzed in the current section, both approaches are combined, and alongside the current knowledge-enhancing efforts active for 40 years, supplementary knowledge-enhancing efforts are introduced to observe the dynamics of the key variables. In this vein, three scenarios as described in Table 23 are analyzed.

Table 23. Scenarios regarding adding extra knowledge-enhancing efforts for adults to the base run.

Scenario	The starting time of the additional program	Duration of the additional program (year)	Effectiveness of the additional program
KA9	2023	40	0.2
KA10	2023	40	0.5
KA11	2023	40	0.8

Within this set of scenarios, the population of well-informed adults surpasses the numbers observed in the two previously analyzed sets, owing to the extensive and prolonged knowledge-enhancing efforts specifically targeted at the adult population. However, as can be seen in Figure 45(a), the higher the effectiveness of the extra knowledge-enhancing program, the lower the slope of the well-informed adult population after 2050. This highlights that if knowledge-enhancing programs in place are adequately high, a greater number of people are educated at an earlier time and a lower number of people remain to be well-informed later. This is advantageous for the entire society, particularly in terms of promoting technologies that facilitate the transition towards CE and sustainability.

In line with the higher number of with the larger population of well-informed individuals in scenario KA11, which has the highest level of effectiveness of knowledge enhancement activities effectiveness, this scenario also demonstrates the highest number of app users, as shown in Figure 45(b). A clear s-shaped curve can be seen in this figure in all three presented scenarios, highlighting the success of the app in the market in terms of the number of users. According to the results illustrated in Figure 45(c), there is a rise in the average number of food bags saved from 2021 to 2023, attributed to knowledge-enhancing programs aligned with the current activities included in the TGTG’s pact. From 2030 onwards, the increase in the average number of saved food bags is influenced by both the current knowledge-enhancing efforts that last until 2063 and additional knowledge-enhancing initiatives during this period. Consequently, as anticipated, the average number of food bags per user per year in 2060 within this scenario surpasses the numbers presented in Figure 43(b), exceeding a noteworthy 2 saved food bags per user. This substantial increase, from 0.36 in 2021 to more than 2.04 in 2060, holds great promise.

Accordingly, the amount of FW prevented, the total CO_2 emissions prevented, and TGTG performance are positively influenced by accounting for additional knowledge-enhancing activities. For instance, scenarios KA11, KA10, and KA9 result in 46,010,200, 42,338,900, and 34,153,600 kg of FW prevented per year in 2060, while this amount in the base run is 11,272,400 kg per year in 2060, as shown in Figure 46(a). Hence, the performance of TGTG experiences a substantial improvement, reaching 0.029 in 2060 within scenario KA11, in comparison with the base run that yields a value of 0.007 in 2060, as illustrated in Figure 46(c). It is important to highlight that while the curve representing scenario KA11 in Figure 46(a) and Figure 46(b) appears to flatten out after around 2050, this scenario still maintains a positive impact on the FSP performance due to the continuous increase in the average number of food bags saved per user.

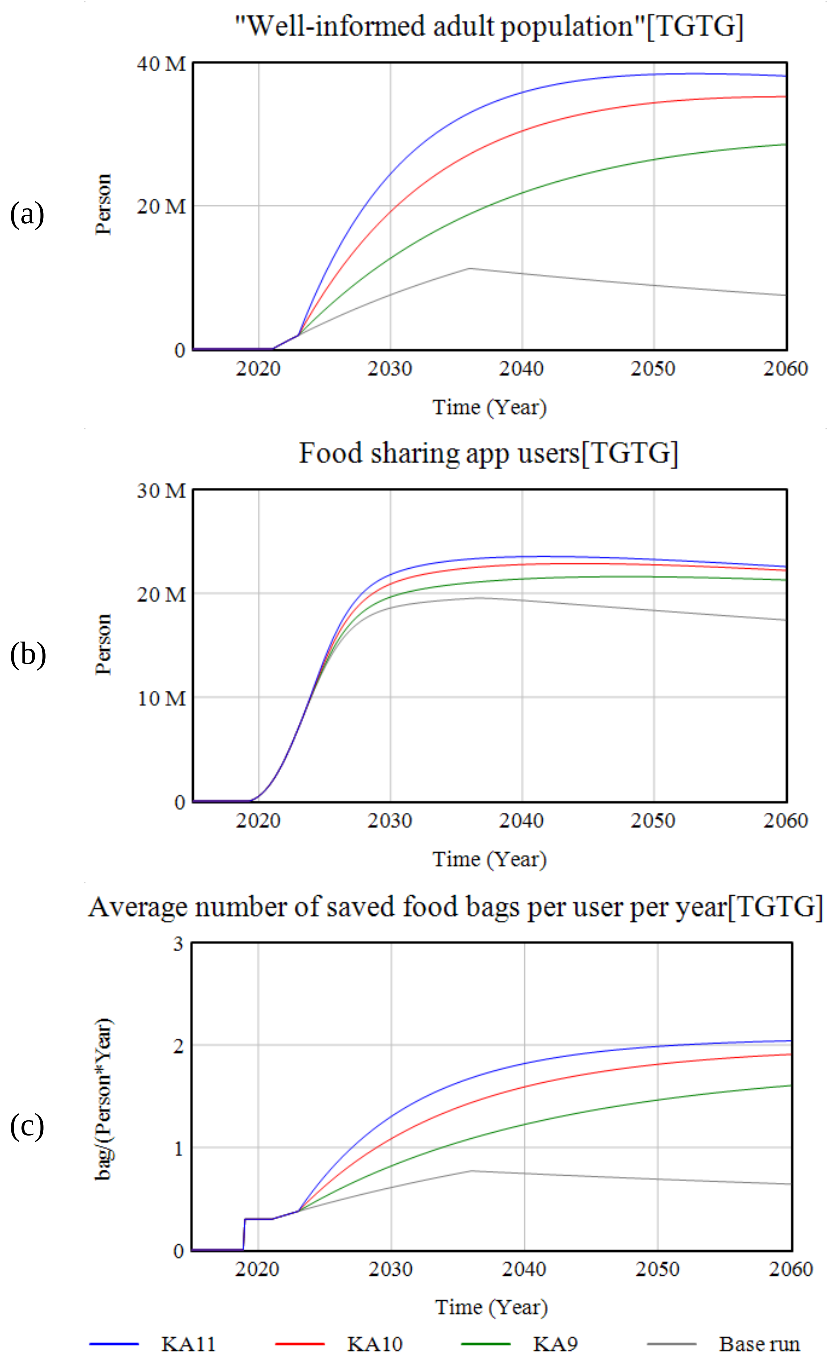


Figure 45. The effect of extensive knowledge-enhancing programs for adults on the number of well-informed adult population (a), the number of TGTG users (b), and the average number of saved food bags per person per year (c).

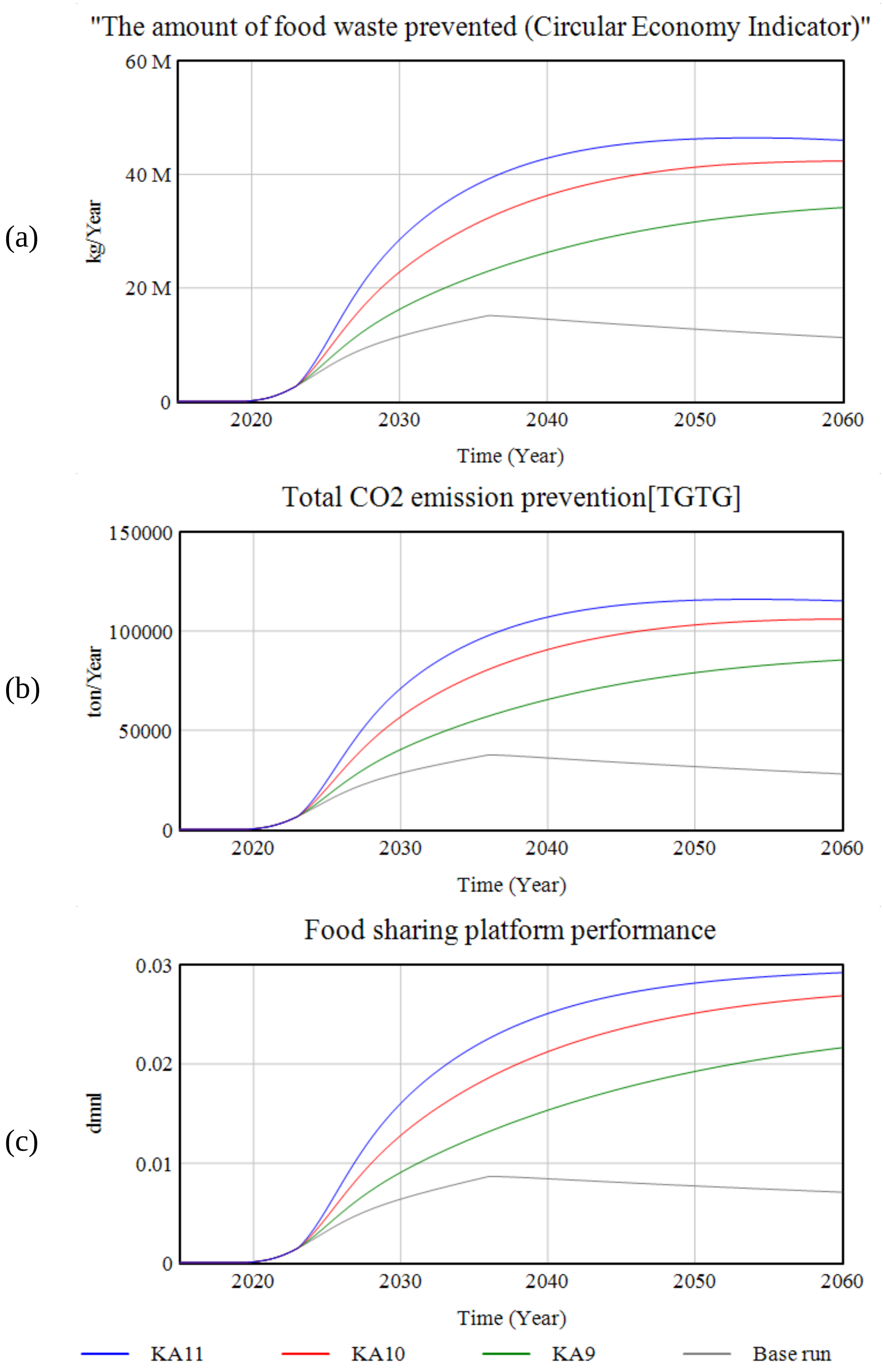


Figure 46. The effect of extensive knowledge-enhancing programs for adults on the amount of FW prevented (the CE indicator) (a), the total CO_2 emission prevention (b), and TGTG performance (c).

In summary, the scenarios analyzed in section 9.3 highlight the significant role of informing adults in improving (i) the number of users, and (ii) the amount of saved food bags per user per year, which leads to enhancing the performance of the food sharing app, and accordingly FW and CO_2 emissions prevention. Unlike the marketing campaign, which is adequately in place and works effectively, knowledge-enhancing programs and activities should be strengthened to contribute to the CE and FW prevention more effectively.

9.4. Knowledge-enhancing programs for children

Although schools have been considered as one of the main pillars in the TGTG's "pact against food waste" launched in 2021, and there are some materials available for schools and training under-aged population, there is no adequate report on knowledge-enhancing activities in schools and their impacts regarding food sharing apps and their applications and contributions. Therefore, this section, this section assumes that no substantial knowledge-enhancing activities have been conducted for the under-aged population in this context thus far. Consequently, knowledge-enhancing activities for individuals under the age of 18 regarding food sharing are initiated in 2023.

The model considers knowledge enhancement for the entire population under the age of 18, extending beyond children in schools. Besides, as mentioned in Chapter 8, the assumption of perfect mixing applies to all stocks in the model, addressing an equal chance for all under-aged individuals to receive training. Therefore, a significant amount of time is required for knowledge enhancement among the under-aged population to see a consistent trend of increasing the number of well-informed adults. Based on this premise, various scenarios analyzing knowledge enhancement among the under-aged population are examined, as reported in table 23.

Table 24. Scenarios regarding knowledge enhancement among the under-aged population.

Scenario	Starting time	Duration	Effectiveness
KU1	2023	30	0.2
KU2	2023	30	0.5
KU3	2023	30	0.8
KU4	2023	40	0.2
KU5	2023	40	0.5
KU6	2023	40	0.8

Based on the analysis provided in section 8.2, higher knowledge-enhancement effectiveness for the under-aged population results in a higher number of well-informed children in an earlier time. Furthermore, keeping the knowledge-enhancing activities for children for a longer period keeps the number of well-informed children higher. Figure 47 shows the effect of the introduced scenarios regarding under-aged knowledge enhancement on the number of well-informed adults. These scenarios are applied to the base run of the model. Therefore, as can be seen in Figure 47, there is a sharp increase in the number of well-informed adults by 2036, which is mainly due to knowledge enhancement among adults during this period. During this period, the impact of training and educating children on the slope of this line is relatively minimal. This is due to the time required for well-informed children to transition into well-informed adults who can actively participate in and utilize the platform. Consequently, the effect of knowledge enhancement and education among children is not immediately reflected in the increase of well-informed adults joining the platform. After 2036, a sharp decrease in the number of well-informed adults is observed in all scenarios. However, scenarios with higher knowledge enhancement effectiveness for children result in a higher number of well-informed adults. Besides, as expected, the number of well-informed adults begins to decline after the conclusion of the 30-year knowledge-enhancing program.

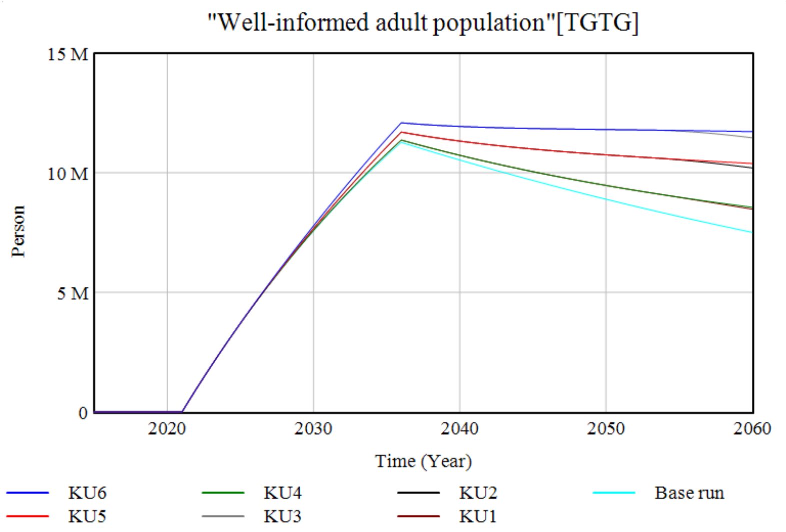


Figure 47. The effect of knowledge-enhancement among under-aged population on the well-informed adult population.

Figure 48(a) denotes the effect of knowledge enhancement among children on the number of app users. While scenarios with higher effectiveness of knowledge enhancement lead to a greater increase in the number of well-informed adults, the corresponding increase in the number of users is not as pronounced. This is because (i) not all well-informed people decide to use the app, and (ii) some of the well-informed population might already be a member of the platform. Hence, the increase in the number of well-informed adults is not proportional to the increase in the number of users. Moreover, as can be seen in Figure 48(a), the results of keeping knowledge-enhancing activities for children in place for 30 and 40 years are very close to each other in terms of the number of users. Regarding the average number of saved food bags per user, similar dynamics as the dynamics in well-informed adults is observed but with a different scale. Knowledge enhancement among children in each of the mentioned scenarios improves the number of average foods saved per user in comparison with the base run, as shown in Figure 48(b).

(a)

(b)

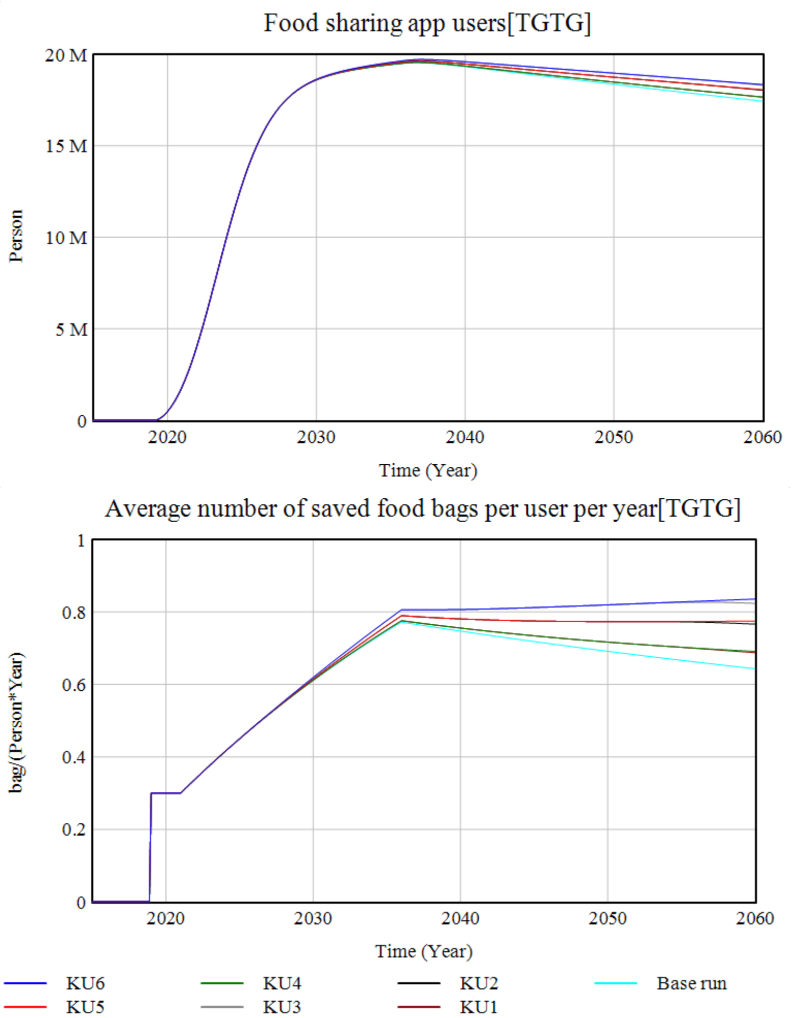


Figure 48. The effect of knowledge enhancement among the under-aged population on the number of TGTG users (a) and the number of saved food bags per person per year (b).

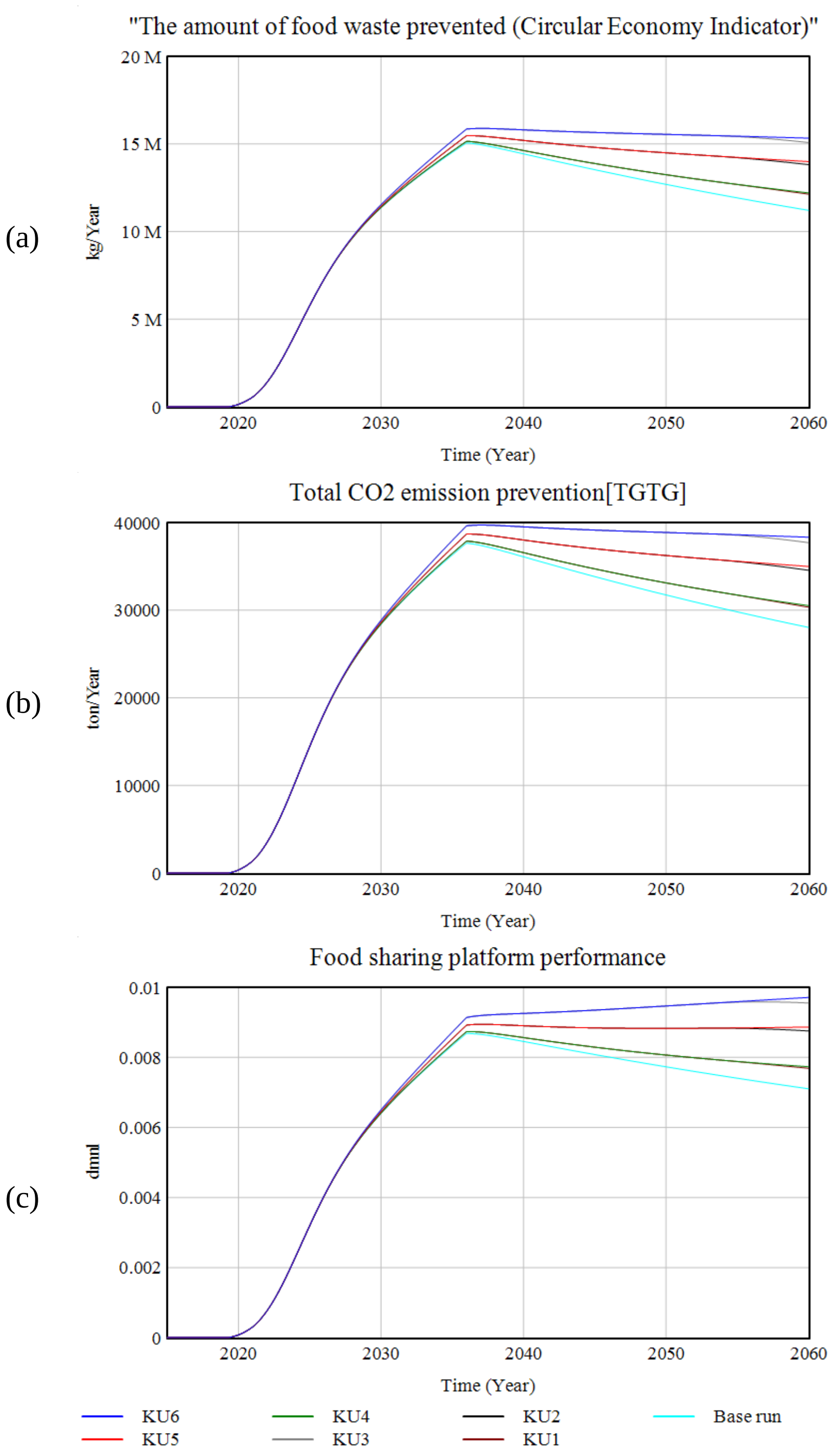


Figure 49. The effect of knowledge enhancement among the under-aged population on the amount of FW prevented (the CE indicator) (a), the total CO_2 emission prevention (b), and TGTG performance (c).

To conclude, although knowledge enhancement regarding FW and FSPs among children is effective and may help improve the indicators in the model in the long term, its effect on the system is not as much as knowledge enhancement among adults by 2060. However, since children are future potential users of the app, knowledge enhancement among children must be taken into account as already noticed in the TGTG's "pact against food waste".

9.5. Policy recommendation

Analysis in Section 9.2 showed that the current marketing campaign for TGTG is strong, adequate, and effective. Hence, keeping this marketing force active for almost 10 years, as in the simulation base run, can result in a successful market for this rapidly growing app in terms of the number of users. However, the mission of this platform is "To make sure good food gets eaten, not wasted" (TGTG, 2022a), thus, in addition to the number of users, the amount of FW prevented by this app should be taken into account when evaluating its success. Analyzing scenarios regarding knowledge enhancement among adults in line with the TGTG's pact against FW and adding knowledge-enhancing programs for the under-aged population in Sections 9.3 and 9.4 revealed that longer-period and more effective knowledge-enhancing programs can still increase the number of app users by increasing their knowledge about the food sharing app and its positive impact on the environment and transitioning towards a CE. More importantly, effective knowledge-enhancing programs can encourage the app users to use the app more frequently, by (i) highlighting the role users can play in saving the environment, and (ii), increasing their knowledge about the rationale behind the FSP and leveraging their awareness about food best time to use and expiration labeling, as already considered by the TGTG platform. Therefore, even if the TGTG app reaches its maximum potential user base, knowledge-enhancing programs can continue to enhance the app's appeal and encourage more frequent usage, resulting in greater prevention of FW.

On this basis, a general policy is recommended and tested in different scenarios in this section and its overall impact on the environmental indicators, including the amount of FW prevented (the CE indicator) and the amount of CO_2 emission prevented, as well as the FSP performance is analyzed. Since current marketing activities (including all forms of marketing and social media activities) are already effective, the recommended policy mainly focuses on knowledge-enhancing activities, both for adults and the under-aged population. Although the under-aged population is not eligible to use the app directly, training this segment of the population increases their awareness and turns them into potential users in the future. It should be highlighted that in the developed model, the potential effects that well-informed adults may have on children, and the effect that well-informed children can have on their families are not taken into account; however, it deserves more investigation from the standpoint of social sciences and can be added to the model in future.

Figure 50 presents a comparison between the estimated FSP performance in the year 2060, based on the discussed scenarios KA2, KA8, KA11, and KU6 . As can be seen in this figure, the effect of knowledge enhancement among the individuals younger than 18 on the TGTG platform performance in 2060 is far lower than scenarios related to improved knowledge-enhancing activities for adults. The main reason is the time lag that the under-aged population requires for maturing, which makes the knowledge enhancing efforts less effective in the near future. Furthermore, a comparison between the scenarios related to the knowledge enhancement among adults shows that a significant difference exists between the result of scenario KA2 and the result of scenarios KA8 and KA11, which contain extra knowledge-enhancing efforts. This is while the outcome of implementing scenarios KA8 and KA11 on the TGTG platform performance in 2060 is very close to each other.

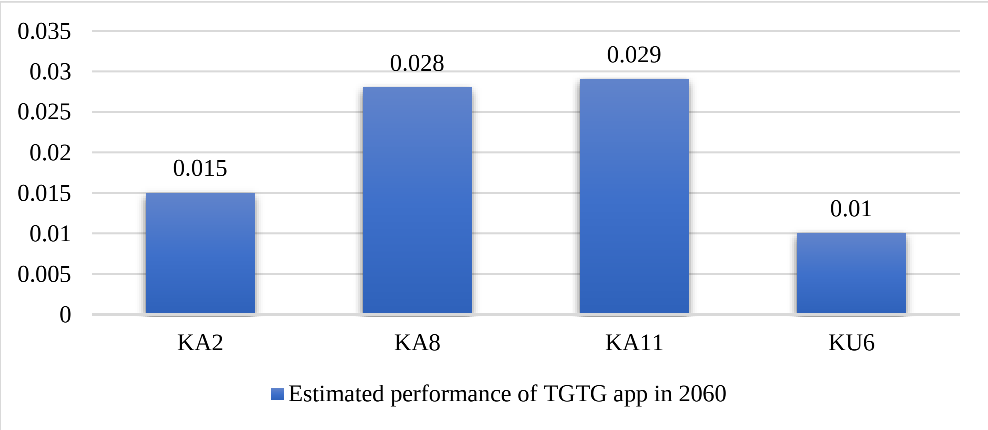


Figure 50. The estimated performance of TGTG FSP in Italy in 2060 in selected scenarios.

The maximum value for performance is 1; however, as the FW in supermarkets and shops that can be prevented constitutes a small fraction of the total amount of FW in Italy, very high performance cannot be expected for TGTG platform. Nevertheless, the higher the performance of this platform in terms of FW prevention, the more favorable the app is.

Based on the developed model and the analyzed scenarios, a potential policy to improve the performance of TGTG FSP as much as possible could be to keep the current marketing efforts in place for 10 years, as it is found to be efficient and adequate, and consider extensive knowledge-enhancing programs for all population, both children and adults. Although knowledge-enhancing programs for children may have a lower impact on the number of users and the number of foods saved in comparison with other scenarios presented in Figure 50, as children will build the future of societies and will become future potential users of sharing platforms, it is very important to invest on their knowledge-enhancement. The effect of training and educating children will be observed at a later time in the future.

In order to evaluate the impact of the recommended policy on the market and the environment, this policy is tested in different scenarios as reported in Table 25. High, average, and low knowledge enhancement effectiveness are set to 0.8, 0.5, and 0.2 in the model, respectively.

Table 25. Scenarios related to the recommended policy.

	Knowledge enhancement among adults				**Knowledge enhancement among children**		
	Currently active programs	*Additional programs*			*Additional programs*		
	Duration	Start	Duration	Effectiveness	Start	Duration	Effectiveness
Scenario A	Until 2060	2023	Until 2060	high	2023	Until 2060	high
Scenario B	Until 2060	2023	Until 2060	high	2023	Until 2060	average
Scenario C	Until 2060	2023	Until 2060	average	2023	Until 2060	average
Scenario D	Until 2060	2023	Until 2060	average	2023	Until 2060	high
Scenario E	Until 2060	2023	Until 2060	high	2023	Until 2060	low

As can be seen in Figure 51(a), scenario A results in the highest number of well-informed adults, followed by scenario B. In both scenarios, the knowledge-enhancing programs for adults are highly effective. However, scenario B has a lower effectiveness of knowledge-enhancing programs for the under-aged population compared to scenario A, leading to approximately 420,000 fewer well-informed adults in 2060. The number of well-informed adults in these scenarios is significantly higher than that of the base run, which is approximately 7.513 million. The same order of scenarios can be seen in Figure 51(b), which illustrates the number of users. However, the number of app users in 2060 in scenarios A and B are estimated to be approximately 22.752 million and 22.703 million, respectively, which is significantly higher than the number of users in the base run (17.524 million). The number of users start to decrease starting from the year 2047, which can be linked to the reduction of population in Italy. Hence, the recommended policy containing knowledge-enhancing programs for both adults and the under-aged population can be considered a winning policy in terms of the number of users, with a significantly higher number of future users in comparison with the base run.

(a)

(b)

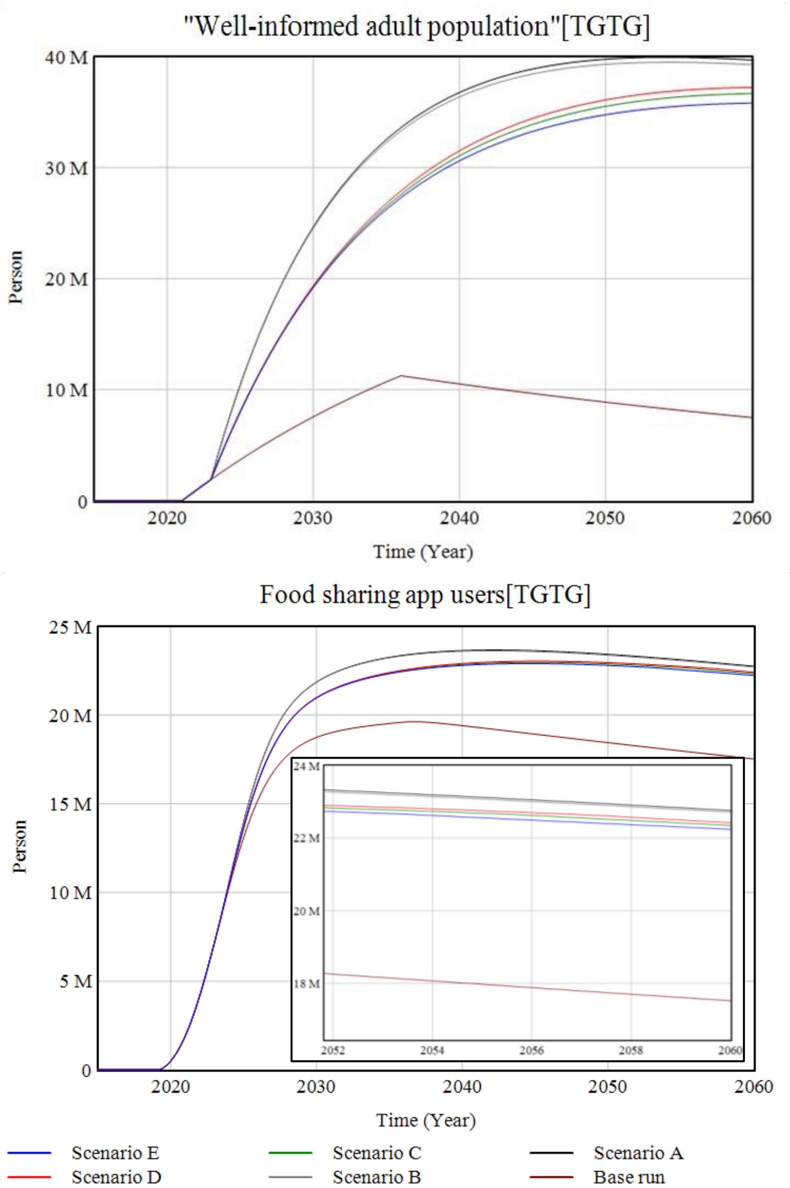


Figure 51. The number of well-informed adults (a) and TGTG food sharing app users (b) in Italy by applying the recommended policy.

In order to analyze the impacts of implementing this policy, the values of the key variables in 2060 are presented in Table 26. As can be seen in this table, all scenarios perform significantly better than the base run in terms of the average number of annual food bags saved by each user, total number of saved food bags, total amount of FW prevented, total CO_2 emission prevented, and the food sharing app performance. However, scenario A is also the best scenario in terms of environmental indicators.

Table 26. Values of selected indicators in 2060 by applying various scenarios of the recommended policy.

Indicator	Base run	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
The average number of saved food bags per user per year	0.643	2.113	2.094	1.975	2.001	1.936
Total number of saved food bags	11.272 million	48.081 million	47.541 million	44.132 million	44.846 million	43.049 million
The amount of FW prevented (tons)	11,272.4	48,081.4	47,541.3	44,131.6	44,846.2	43049
Total CO2 emission prevention (tons)	28,181	120,203	118,853	110,329	112,115	107622
FSP performance	0.0071	0.0305	0.0301	0.0279	0.0284	0.0273

Figure 52 shows the dynamics in the TGTG platform performance in response to applying the analyzed scenarios, which can be considered the most crucial indicator to evaluate the contribution of TGTG FSP in transitioning towards the CE. As can be seen in this figure, by implementing each of the proposed scenarios, the performance of the TGTG FSP increases. Similar to the number of users, this indicator is higher if scenario A is prioritized to be implemented. The promising point in this figure is the increasing trend of platform performance that keeps continuing until the end of the simulation period.

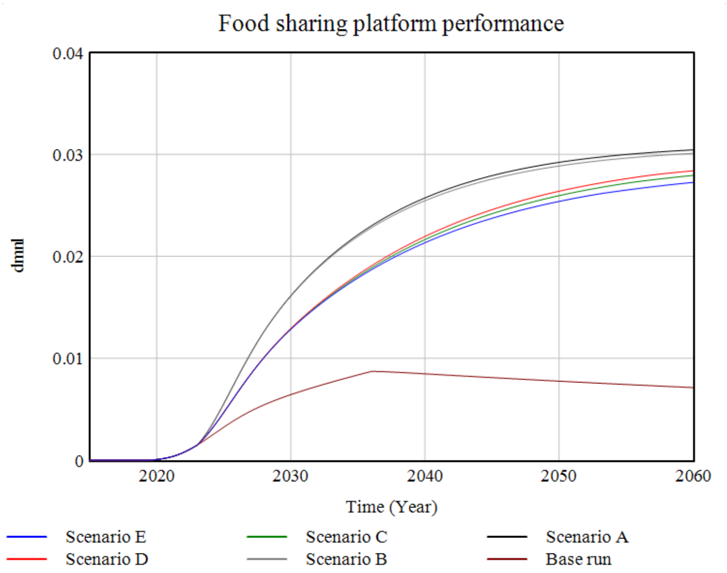


Figure 52. The performance of TGTG FSP by applying the recommended policy.

To provide a clearer image of the potential role TGTG can play in preventing FW and transitioning towards the CE, Figure 53 shows the share of FW prevented through TGTG platform in 2060 from the total FW in Italy by implementing scenario A and also the base run.

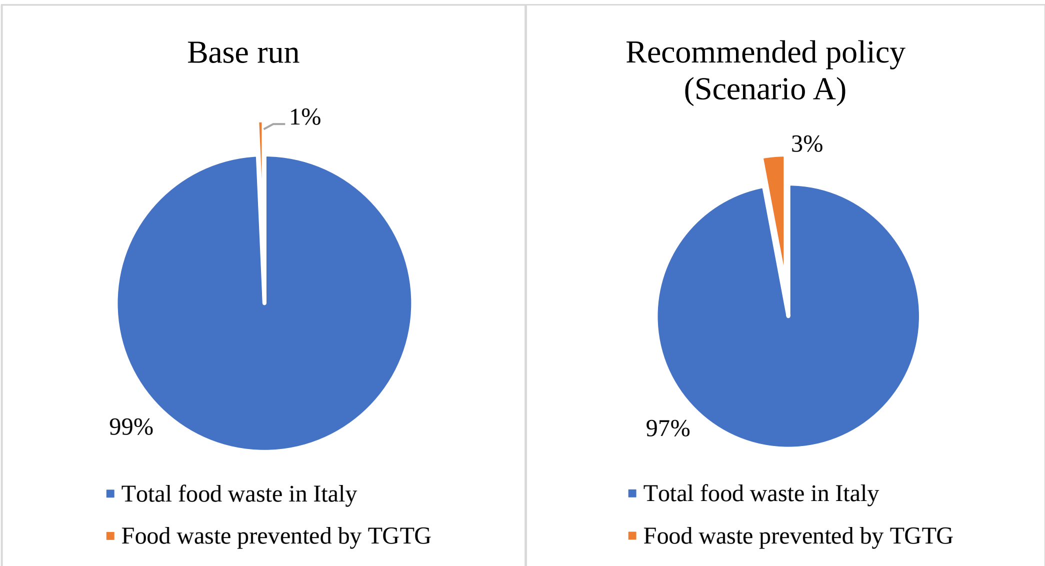


Figure 53. The share of FW prevented by using TGTG food sharing app from the total FW in Italy.

As can be seen in Figure 53, the share of FW that can be prevented from the total FW in Italy in 2060 can reach approximately 3% by keeping the current effective marketing campaigns for 10 years, continuing the current knowledge-enhancing programs for supermarket staff and other people in the society by 2060, and at the same time, putting highly effective knowledge-enhancing programs both for adults and for under-aged population into force. Although scenario A has the best outcome among the analyzed scenarios, implementing any other scenario under the umbrella of the recommended policy, containing strong knowledge-enhancing programs for all the population, continuing the currently active knowledge-enhancing programs until 2060, and keeping the current strong social media and marketing activities in place for 10 years, can significantly increase the performance of TGTG FSP in preventing FW. This can represent a significant contribution of a digital platform in transitioning towards the CE by preventing a huge amount of food products from being wasted.

However, these activities require strong support from policymakers, regulators, and governments that have been also addressed in the TGTG's pact against food waste. In fact, the role of policymakers, regulators, and governments in enhancing FW prevention and management is essential for the successful transition to a CE. They can establish regulatory frameworks encompassing FW reduction targets and standards, both for businesses and households, to incentivize the reduction of food waste. To make more informed decisions, policymakers can establish systems for collecting and analyzing FW data and require food businesses to report their FW data and their FW reduction efforts. Providing financial incentives for investing in FW reduction technologies and practices, funding for research and innovation in FW reduction technologies, legislative actions to redistribute surplus food, comprehensive CE legislation, and standardizing date labeling can accelerate progress in this area. Furthermore, governments can collaborate with businesses, NGOs, and other stakeholders to develop and implement food waste reduction initiatives through public-private partnership and international cooperation.

Beyond direct regulation and supports, policymakers should also emphasize promoting sustainable production and consumption practices more broadly. In this regard, governments and policymakers can run public campaigns to educate consumers about FW reduction, proper storage, and smart consumption, and support training programs for businesses in FW prevention techniques. Educating society about sustainable consumption, part of which is linked with sharing platforms, and providing support in adopting these technologies can facilitate the transitioning towards sustainable development and tackling climate change by encouraging a shift in people's lifestyles.

Section V

Conclusion

Chapter 10: Concluding Remarks, Limitations, and Future Research Agenda

This chapter concludes the thesis by presenting the thesis remarks, highlighting its main findings and contributions to theory and practice, describing the limitations, and proposing future research avenues for further development.

10.1. Concluding remarks

Understanding the CE as a system attribute rather than an individual product or service characteristic underscores the necessity for more knowledge on how to innovate toward circular ecosystems (Konietzko et al., 2020). In this regard, Konietzko et al. (2020) proposed a set of principles for circular ecosystem innovation in three categories, namely collaboration among different players, experimentation to organize trial-and-error processes, and platformization to more effectively interact with involved stakeholders to achieve more circularity. Hence, as a progressive move towards establishing a more circular food system, the emergence of digital platforms and their application in different levels of food supply chains has drawn notice. FW, as one of the largest waste streams generated in the world, has brought severe implications for the global economy, the environment, and societies. Hence, sustainable initiatives to reduce FW and loss by rethinking, redesigning, and operating all practices within the food supply chain are crucial in the transition towards a CE in the food sector.

Having scrutinized the FW literature by conducting three different systematic reviews with an up-down approach in the current thesis, the theoretical background of FW research was mapped. In this regard, literature shows that (i) bio-based waste, in particular, FW management practices have appeared as one of the main salient research themes within the waste management domain to implement a CE, which highlights the high potential of the food sector in contributing to the CE transition, (ii) research activities and development efforts in the FW domain have been mainly focused on (1) technological developments in FW treatment systems and biorefinery applications, (2) FW supply chain management towards a CE to address sustainability and environmental concerns, and (3) FW behavior and consumption patterns. However, the provided comprehensive map of FW research in this thesis acknowledges that FW research has paid much attention to FW final disposal, FW valorization, and energy production through the biorefinery domain rather than FW at the consumption level and behavioral aspects of food consumption patterns. On this basis, alternative distribution channels in food supply chains using digital platforms, in particular, digitally enabled FSPs, have recently received attention as a solution to tackle the FW challenge at the consumption level. However, the contribution of the food sharing initiatives to a sustainable circular food supply chain is still unexplored and needs more research and developments.

The number of users of digitally enabled FSPs, in particular, the food sharing for money business models, is considerably increasing. However, it is still not clear how the diffusion of such food sharing apps will take place in the future. In contrast with the increasing number of users, the effective usage of such platforms, referring to the average number of saved food bags per user per year, is often quite low, resulting in a paradox, which calls for further research. Therefore, to shed light on the identified gap, a System Dynamics simulation model was developed in this thesis to specifically answer the following research questions: (i) how would the diffusion of digitally enabled FSPs be in the future?; and (ii) to what extent digitally enabled FSPs can help FW prevention in a CE over time? Then, through testing various scenarios, the effect of different levels of knowledge-enhancing activities and marketing plans on the adoption and performance of such platforms over time was analyzed and discussed. In this regard, the TGTG FSP in Italy, as a well-known food sharing for money app, was studied as a case.

The simulation results showed that TGTG is a successful FSP in terms of adoption by users in Italy. However, the performance of this platform regarding its potential to reduce FW can still improve to a large extent. In this regard, the findings denoted that the current marketing strategy of TGTG is performing effectively, hence, keeping the current marketing campaign for around 10 years will sustain the market share of TGTG. Nevertheless, the training portfolio of TGTG needs more developments and improvements to increase TGTG's performance by enabling more effective usage of the app and, accordingly, more FW prevention. More particularly, (i) the number of users can still grow up using more effective and longer-run knowledge-enhancing plans and programs by increasing the public's knowledge regarding the FW crisis and its adverse implications for the environment, resource efficiency, food security, and hunger, and (ii) even if the number of TGTG users reaches the maximum potential number, knowledge-enhancing programs can still work towards increasing the attractiveness of more frequent usage of the app and save a higher amount of food products from being wasted. Hence, putting knowledge-enhancing activities at the core, a proper policy for TGTG was recommended which can lead to a reduction of approximately 3% in the total FW generated at the country level (Italy) in 2060.

The simulation model developed for the diffusion of TGTG in this thesis is the first diffusion model developed for digitally enabled FSPs in literature. Hence, it can significantly contribute to the CE transition in the food sector through embracing the sharing economy concept. The provided insights shed light on the digitally enabled FSP realm and support policymakers, food supply chain stakeholders, and researchers and practitioners involved in waste management practices to facilitate the CE transition in the food sector.

Although the developed diffusion model was built for the TGTG platform in Italy, it is a general model that can be used for any number of other FSPs in any other region. Therefore, the developed model can guide food supply chain stakeholders and policymakers in incorporating sharing economy in the food sector to (i) reduce FW through FW prevention, (ii) tackle environmental concerns related to the huge amount of FW, and (iii) create strong social communities and use volunteer potential to help food security and poverty alleviation towards achieving sustainable development goals 2 (zero hunger) and 12 (responsible consumption and production).

10.2. Limitations

Through developing the System Dynamics model simulation of TGTG, the current thesis faced two limitations.

Firstly, the main limitation in front of the developed model in the current thesis was the lack of accurate and sufficient data. Data and interactions are considered key assets for online platforms to enable creating value in societies (Konietzko et al., 2019). The providers of sharing economy platforms, in particular, the FSP studied in this thesis (i.e., TGTG), often do not provide access for the public to their database. This has been acknowledged by many scholars, such as Hennig (2019), and Shams Esfandabadi (2022). Hence, the number of active users (i.e., users who have registered in TGTG and making orders to buy food products) was considered the same as the number of users (i.e., people who have registered in TGTG, not necessarily active ones). Besides, the average food saved per person per year was roughly estimated based on an aggregate form rather than detailed according to the total number of users, the total amount of food saved, and the entire duration of the TGTG platform activity in Italy. Therefore, this might lead to inaccuracy in the diffusion model developed and the behavior predicted in this thesis. More accurate data would result in more confidence in the model and accordingly the results would be closer to reality.

Secondly, the developed model did not consider the effect of the COVID-19 pandemic on the adoption of the TGTG platform. Obviously, the pandemic has affected the application of food-related industries and businesses worldwide (Ranjbari et al., 2021b). However, due to the lack of any reliable research on the case of TGTG and COVID-19 implications, the effect of the pandemic outbreak on the level of diffusion of TGTG was not considered in the developed model. Hence, in case of data availability, incorporating the pandemic effects into the built model might provide some insights and more accurate results in further developments in the future.

10.3. Future research agenda

According to the insights provided in the current thesis through a comprehensive literature review and then developing a System Dynamics model simulation for digitally enabled FSPs, implications for future studies are presented in this section. Incorporating the sharing economy concept into the food supply chain, as a potential solution to a CE transition in the food sector, needs more investigations and further development. In this vein, after careful consideration, four mainstreams of research were identified as potential research gaps and directions for future studies to better position the FW management agenda in line with the CE framework. The four research avenues identified herein call for: (i) exploring rebound effects of FSPs, (ii) extending the presented diffusion System Dynamics model for FSPs, (iii) conducting empirical research to better framing food sharing initiatives and assessing their impact, and (iv) employing a mixed approach to simulation modeling, using System Dynamics and agent-based modeling for studying the impact of human behavior on the general dynamics of the system. The subsequent sub-sections provide a detailed exposition of the proposed agenda for advancing future research developments.

10.3.1. Exploring rebound effects of food sharing platforms

Although CE as a solution to achieve sustainable development has gained much attention over recent years, CE initiatives often lead to rebound effects, which adversely impact their sustainability potential (Metic and Pigosso, 2022). For instance, in the case of digitally enabled FSPs, food sharing for money business models, in particular, the rebound effects are arguable. Such platforms have been initiated with the aim of reducing FW through promoting FW prevention in line with the CE principles. In contrast, many argue that although these platforms have provided an opportunity to prevent FW through distributing food surplus, the use of such applications can result in rebound effects, leading to emerging different lines of businesses for retailers to sell more food products. However, given the novelty of the urban FSPs, the contribution of the food sharing initiatives to the CE transition and a sustainable food supply chain is still blurred (Sarti et al., 2017), calling for further investigations. In this regard, as highlighted by Yu et al. (2022) and Meshulam et al. (2022), further research is required to investigate the potential rebound effects of FSPs to see whether the food sold on the platform is effectively a surplus or a planned production.

10.3.2. Extending the presented model to address other unexplored aspects

There are several points regarding the developed diffusion model for TGTG in the current thesis that can be addressed for further extension in future studies. First, although the developed model has covered different dimensions of the FSP adoption, two factors have not been considered as deserved. In this regard, the potential effects that well-informed adults may have on children, and the effect that well-informed children can have on their families to adopt the technology can create additional loops in the model. Considering this element in the developed diffusion model might add useful insight into the system and its behavior, however, it requires conducting surveys and gathering relevant data. Besides, the effect of knowledge-enhancing activities on the attractiveness of adoption and effective usage of the TGTG app was considered linear. Hence, further developments can consider non-linear effects to compare the results.

Moreover, as the presented model is a general diffusion model for FSPs, it can be sued to simulate the diffusion and impacts of other FSPs in other countries, proposing a promising direction for further research. However, unlike the presented reference case of TGTG in Italy, utilizing the present model for other countries with diverse food sharing apps might require the consideration of spillover effect among the available apps. Furthermore, while the presented case addressed a food sharing for money platform, using the model for other food sharing business models may require additional assumptions or relevant data to distinguish between the diffusion of various existing business models.

Finally, considering the rapid pace of technological advancements, such as the emergence of artificial intelligence and industry 5.0, it is crucial to explore their potential impact on market dynamics, user behavior, knowledge enhancement methods, and other relevant aspects. Understanding how these evolutions may influence the diffusion dynamics of FSPs entitles future investigation.

10.3.3. Conducting empirical research to better framing food sharing initiatives and assessing their impact

As described in previous chapters, the FSP domain and its implications and associated challenges lack sufficient empirical research and verifiable evidence. In this regard, more investigation is required to collect reliable data through various types of qualitative and quantitative methods, such as surveys and experimental analyses. In this regard, different players of the FSPs, including potential consumers, businesses, retailers, and platform providers should be considered and scrutinized. On the one hand, designing accurate and concrete surveys to evaluate the behavior, attitudes, and consumption patterns and habits of consumers should be addressed to better establish digitally enabled FSPs and food redistribution systems, especially in the case of peer-to-peer FSPs. On the other hand, collecting relevant data from for-profit and nonprofit organizations and businesses involved in any type of food sharing business model is of high importance to facilitate the adoption of such platforms in the future.

Moreover, although some initial sustainability assessment tools have been proposed by several scholars, such as Mackenzie and Davies (2019) and Michelini et al. (2020), the literature in this area is still in its infancy stage. Therefore, designing sustainability assessment frameworks to evaluate the real impact of FSPs on the triple bottom line of sustainability, including social, environmental, and economic pillars is strongly recommended for future research.

10.3.4. Employing a mixed approach to simulation modeling, using System Dynamics and agent-based modeling

In this research, we have made clear the value of System Dynamics modeling for understanding the behavior of FSPs in terms of their adoption and performance in contributing to the FW prevention and CE transition. However, since each modeling approach can address different decision problems in any field of study, a combination of different modeling methods can potentially serve as a more useful approach in dealing with complex issues (Wei and Shang, 2023). Hence, a hybrid approach to incorporate other simulation models, such as agent-based models, to the developed System Dynamics model in the current research can provide a more detailed evaluation of the diffusion of FSPs. On this basis, complex interactions among different agents within the FSPs, including app users, points of sales (i.e., bars, restaurants, supermarkets, etc.), and authorities can be effectively captured and modeled by agent-based models. Therefore, the results might advance the field and support research and developments in the FSPs arena towards implementing a CE in the food sector.

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