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Towards the Smart Sustainable and Circular Food Supply Chains Through Digital Technologies

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Abstract
Food supply chain management has become a remarkable issue due to the increasing food waste caused by globalization and population growth. It is essential to gain understanding of the drivers of circular economy in food supply chains and investigate stimulating factors in the development of circular food supply chains. Thus, this study conducted a systematic literature review from 2008 to 2020, including an analysis of 137 articles performed on data to answer specific research questions regarding circular food supply chain drivers. Drivers for transition to circular economy in food supply chains are presented in five main categories with 22 sub-drivers. This research contributes to the existing literature by presenting a novel approach to digital transformation in smart food supply chains through the integration of Industry 4.0 technologies. The findings present potential drivers of circular economy in food supply chains for digital transformation. This study also ensures operational efficiencies by digital technologies in food supply chains that can be beneficial for practitioners.

Keywords- Circular economy, Industry 4.0 technologies, Food supply chain, Digital transformation, Smart supply chain.

List of Abbreviations
CE- Circular Economy.
FSCs- Food Supply Chains.
IoT -Internet of Things.
CPS- Cyber-Physical Systems.
BDA- Big Data Analytics.
CC- Cloud Computing.
AI- Artificial Intelligence.
3DP- Three Dimensional Printing.
AGV- Automated Guided Vehicles.
RFID- Radio-Frequency Identification.

1. Introduction

A circular economy (CE) is an industrial system that reflects nature aimed at optimizing resource use and waste reduction through dynamically (Jurgilevich, 2016; Mahroof et al., 2022). CE aims to decrease resource utilization, consumption, and negative environmental impacts of industry by establishing closed-loop systems. A CE is not aiming to reduce waste but also enables the reusing and recycling of the waste in the processes (Genovese et al., 2017). Companies can benefit from CE is to decrease energy costs and reduce supply chain risks. Consumers and users acquire opportunities by hindering obsolescence, and enhancing improved service quality (Ellen MacArthur Foundation, 2013). Eliminating waste by adopting the "closing the loop" perspective provides cost savings and less resource consumption (Tseng et al., 2014; Kirchherr et al., 2018). CE has basic principles: it relies on 'systems thinking' because the main aim is to understand how components influence each other (Abideen et al., 2021a) and observe the relationship of components in a holistic way (Bressanelli et al., 2022). Systems thinking usually give insight into a non-linear system with a feedback mechanism (Ellen MacArthur Foundation, 2015; Joshi and Sharma, 2021). The second principle is to design the product for disassembly and refurbishment to eliminate waste (Farooque et al., 2019). Besides, it aims to optimize the whole system instead of its components, which can also be considered a "design to fit." Another principle is protecting and developing renewable resources and natural capital (Cherrafi et al., 2022). The last principle of CE is that products and by-products must be maximized in the supply chain. CE activities can be integrated into a different stage of the supply chain by encouraging manufacturers to design products by considering disassembly and refurbishment to eliminate waste, providing the development of food supply chains (FSCs) that meet demand without waste and loss establishing refurbishments system (Lerman et al., 2022). Moreover, it can be achieved by incentivizing businesses and managers to provide material from closed loops and enhancing policymakers' awareness.

The effective management of natural resources and impacts on the environment of the production process have become significant issues in the world, especially in emerging economies (Banik et al., 2022). Increasing population and economic growth have necessitated the efficient utilization of resources. According to OECD, the global middle class will double by 2030; therefore, sustainability and CE should be considered in all societies to meet the demand for resource-intensive goods (Esposito et al., 2018; Kumar et al., 2019). Climate change, the rapid depletion of resources, and the necessity of their practical use have led to the concept of sustainability and CE (Lahane et al., 2020). The CE paradigm provided a framework for adopting sustainability activities (Genovese et al., 2017; Dossa et al., 2022). Besides, as resources become more valuable, governments and sectors have adopted the philosophy of "CE," aiming "reduction, reuse, repair and recycling to ensure resource efficiency" (Genovese et al., 2017; de la Caba et al., 2019). The CE can be seen as an operational tool to achieve economic, environmental, and social sustainability (Avraamidou et al., 2020). CE aims to deal with waste and emission problems in all supply chain processes from production to consumption by presenting reuse, recycling, regenerative, and environmentally friendly product (Tseng et al., 2020). It achieves this objective by ensuring that its products, components, and materials always deliver optimal benefits while minimizing or eliminating waste. Similarly, the goal of CE (Continuous Improvement) is to enhance resource value through its involvement in waste management and material recycling (Paes et al., 2019; Zhu et al., 2019). Businesses should make structural changes in the transition to the CE as well. Drivers can be considered a critical factor for this transition (Matharu et al., 2016; Lahane et al., 2020).

CE needs to be integrated with processes in the FSCs. Thus, there are various drivers for the transition to CE in the FSCs, such as increasing consumer awareness, providing high-quality and healthy food, increasing the efficiency of materials and energy usage, and improving productivity using smart decision tool and models. Besides, FSCs management has become a remarkable issue due to the increasing population growth and ascending in food demand. Because of the urbanization and changed consumption behaviors, food waste increased tremendously in the world (Priefer et al., 2016; Korhonen et al., 2018). Thus, this problem becomes a global problem that affects both developed and developing countries in a similar vein regarding food safety, security, and sustainability issues (FAO, 2019; Walia and Sanders, 2019). In addition, there is no accurate estimate of food waste or loss, and approximately a third of food waste in the world has been lost in the different stages, which include farm-to-fork of FSCs. In alignment with the United Nations Sustainable Development Goal 12, which is to ensure to provide sustainable consumption and production behaviors, all countries in the world are committed to halve the per capita food waste at the retail and consumption level and, in the same breath, decreasing the waste by 2030 (Corrado and Sala, 2018). Food waste is a global challenge that must be considered as a whole. According to the UN, it is expected that the world population will increase to 9.8 billion by 2050, which will create significant food supply problems (UNDESA, 2017), considering the fact that higher than 820 million people lack the necessary reach to food for a healthy life globally (FAO, 2019). As previously stated, the generation of food waste often lacks detailed information about the quantity of waste, and the root causes of food waste are not thoroughly explored (Mangla et al., 2018; Jagtap and Rahimifard, 2019). Improved operational efficiencies at all stages of a supply chain or management practices improve overall effectiveness (Irani and Sharif, 2018). Developing CE solutions is inevitable in the food sector, which is most affected by increased population, and lack of resources. Accordingly, the primary motivation of this study is to provide a systematic perspective by considering economic, environmental, social, managerial, technological, and regulatory drivers of CE in FSCs to decrease food waste, improve food safety/quality and enhance efficiency in the FSCs.

Consequently, this paper aims to provide insight into current literature by determining drivers of CE in FSCs and sub-drivers that stimulate CE in FSCs and analyzing the interactions between CE dimensions & supply chain stages, sub-sectors of food within the FSCs context. Besides, the potential use of Industry 4.0 technologies for the CE drivers in FSCs is proposed to provide digital transformation in the FSCs.
Therefore, this paper stands on the RQs:

RQ1. What are the drivers of implementing CE dimensions in the FSCs?
RQ2. What are the relationships among CE dimensions between supply chain stages and sub-sectors of the food industry?
RQ3. What are the potential benefits of digitalization to establish CE in FSCs?

The implementation of CE requires a depth analysis of interactions among stakeholders of the FSCs. Thus, policymakers and practitioners should analyze the supply chain based on the systems approach. In that sense, the drivers are vital factors that need to be investigated to reveal the potential need and opportunities within CE implementation. Therefore, the contribution of this study can be grouped into three folds. Initially, this study depicts both drivers and sub-drivers of CE in FSCs. Secondly, it reveals the relationships between CE dimensions, supply chain stages, and sub-sectors of the food industry. Finally, this study contributes to the implementation of CE in FSCs by proposing implications within digitalization that can be considered a guide to realizing benefits of CE in the food industry.

To achieve these goals, the article is structured as follows: After the introduction part, review methodology and results of the study is discussed in second and third sections, respectively. Section 4 includes discussions and implications of this study. Finally, section 5 involves the conclusions of this study.

Accordingly, the review methodology is discussed in the next section.

2. Review Methodology

This study conducts a systematic literature review to ensure in-depth insight into drivers of CE in FSCs and analyses how CE can stimulate food-supply chains. The systematic literature review is applied to provide comprehensive and reproducible knowledge on the specific topic. It produces credible sources by reducing bias and providing deep insight into the issue under consideration. Transparency of the methodology is very high since research strategies are clearly defined at the beginning of the processes. However, sometimes it is considered as a more time-consuming method than the other type of review. Besides, sometimes it can create a bias due to the not including some sources (such as government reports, secondary reports, etc.). This paper conducted the systematic literature review process that includes six stages. In phase I, existing studies related to this topic are explored. Then, the literature gap is defined based on the literature review. In phase 3, called the define stage, the need for this study is determined using research objectives, questions, and a literature review based on the criteria. Stage 4, data extraction from the selected documents is conducted in this stage. Phase 5 is the results and discussion stage, which includes the data analysis and results. Finally, the implications stage proposes implications for managers, policymakers, and academia. The conceptual framework of this study is shown in Figure 1.

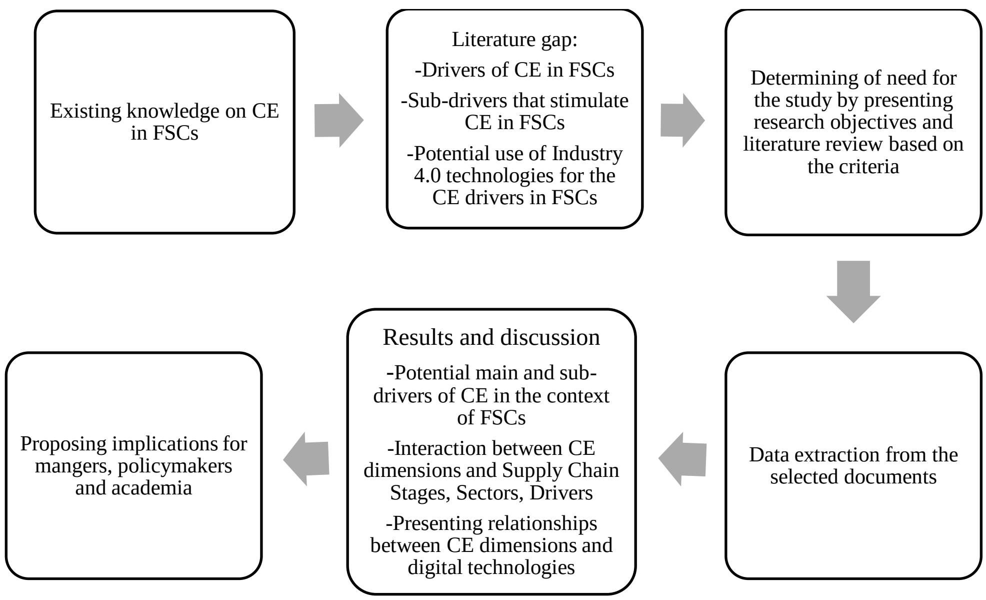

Figure 1. Conceptual framework of this study.

Table 1. Literature review criteria.

Criteria	***Identification***
Period	From 2008 to 2020
Boolean Operators	**AND** between keywords; **OR** between database search fields.
Search strings	"Food supply chain" **AND** "circular economy" **AND** "drivers" **OR** "enablers" **AND** "Reuse", **OR** "Recycle", "Refuse", **OR** "Reduce", **OR** "Refurbish", **OR** "Repair", "Remanufacturing", **OR** "Recover", OR "Redesign", "Rethink" **OR** "Repurpose" **OR** "Resolve" **OR** "6R" **OR** "9R."
Language	English
Publication Type	Academic journals and conference papers

The literature review criteria of this study are summarized in Table 1. This review includes only academic journals and conference papers, excluding books, research reports, etc. This study consists of different publications published in English from 2008 to 2020. In this literature review, two primary databases are used, Scopus and WOS. Research strings that are used in this study: “Food supply chain” AND “circular economy” AND “drivers” OR “enablers” AND “Reuse”, OR “Recycle”, “Refuse”, OR “Reduce”, OR “Refurbish”, OR “Repair”, “Remanufacturing”, OR “Recover”, OR “Redesign”, “Rethink” OR “Repurpose” OR “Resolve” OR “6R” OR “9R”.

In the initial step, 500 articles are collected using determined databases based on proposed research strings. Following this process, 102 articles are eliminated by reviewing of title and abstract of the papers. Then, remaining 261 articles have been investigated by considering research objectives. After these elimination process, remaining 137 articles in aligned with the research objectives that is presented in the introduction section of this study has been investigated. The literature search, evaluation, and inclusion process are presented in Figure 2.

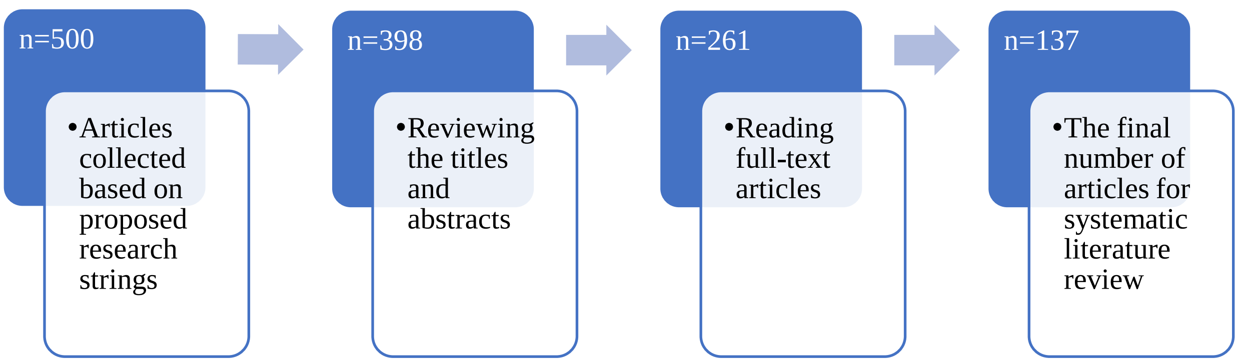

Figure 2. Literature search, evaluation, and inclusion process.

3. Results of the Study

This section includes a further descriptive analysis of the selected articles, such as the number of publications, methods used in the study, CE dimensions of publications, focus area used in publications, distribution of FSCs stages, distribution of food sub-sectors based on the CE dimensions, articles by continents and regions, intersection between the methods and different CE dimensions considering drivers of CE dimension in FSCs.

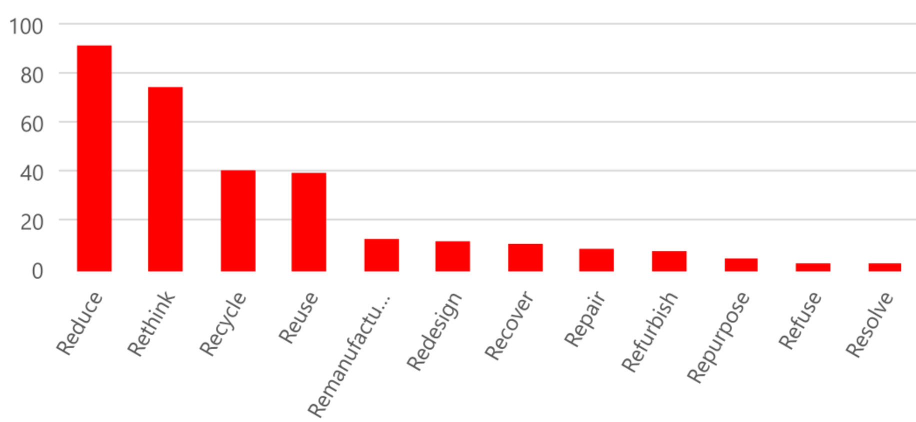

Figure 3. Number of publications considering CE dimensions.

The CE dimensions of publications are presented in Figure 3. This study considers CE dimensions: “reuse”, “recycle”, “refuse”, “reduce”, “refurbish”, “remanufacturing”, “repair”, “recover”, “redesign”, “rethink”, “repurpose”, and “resolve”. According to this figure, “reduce” is mainly used for CE dimensions corresponding to 65, 7. The primary goal of implementing CE in the FSCs context is to reduce food waste and loss. The most frequently used CE principles followed by “reduce” are “rethink”, “recycle”, “reuse”, and “remanufacturing” and “redesign” with 53, 3%, 28, 5%, 27, 7%, 8%, and 7, 3 %, respectively. Moreover, “recover” (6, 6%), “repair” (5, 1%), “refurbish” (4, 4%), and “repurpose” (2, 2%) are less frequently used as a CE principle based on selected articles. “Resolve” and “refuse” are hardly ever dealt with in the context of CE dimensions. The main drivers of CE are reducing food waste and increasing CE adaption of production processes; therefore, studies mainly focus on “reduce” and “rethink” considering CE dimensions. Adaption of CE and closed loop supply chains approach should only be handled at the design stage of the supply chain, and the process should be designed following this structure. For this reason, the “rethink” concept is seen as the CE dimension that is most discussed.

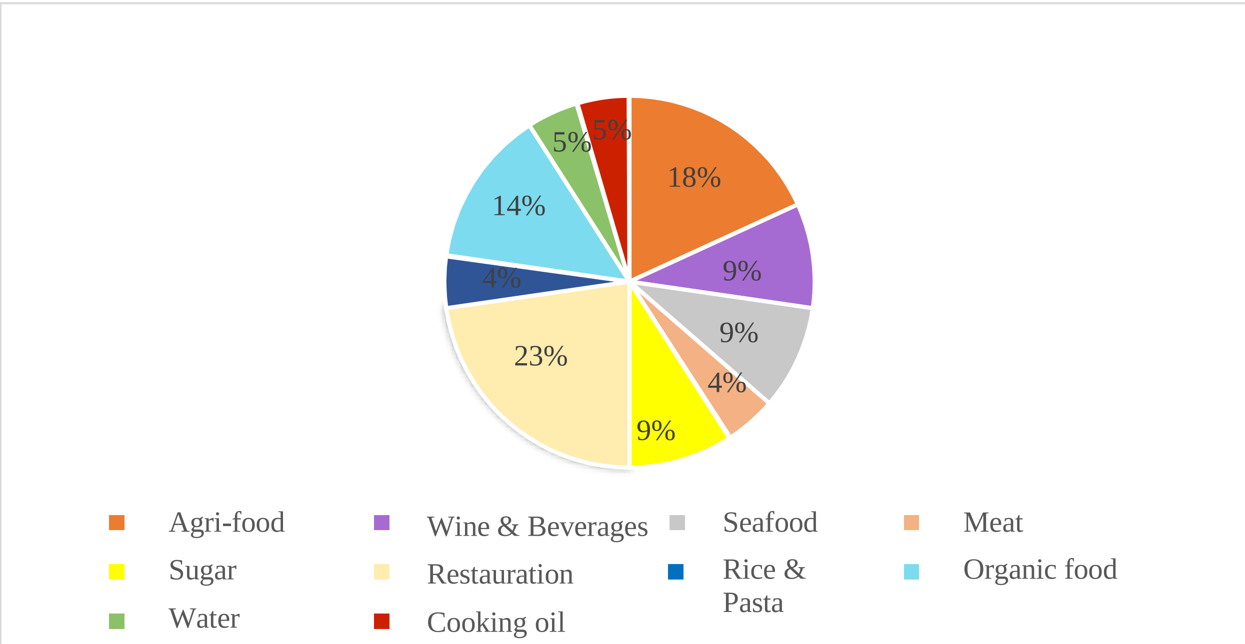

Figure 4. Distribution of food sub-sectors based on the CE dimensions.

As shown in Figure 4, the graph illustrates the subsectors represented in the articles of the systematic review studies. 23 % of them are related to restauration, giving us the highest percentage among the others, followed by agri-food with an 18% and organic food waste with a 14%. Then, the other subsectors with similar percentages include wine and beverages, seafood, meat, sugar, rice and pasta, water, and cooking oil.

As presented in Figure 5, 59% of these articles are studies which are conducted in the European countries, including Italy (28%), the UK (18%), Germany, Portugal, and Spain. It is followed by East Asian countries, including China and Japan, with a total percentage of 17% and North America with 11%. The others are from the Middle East region, Australia and South America. This figure suggests that European countries prioritize transitioning to CE in the FSCs. Besides, East Asia are enthusiastically exploring solutions to diminish food loss and waste. Thus, local government, policymakers and scientists in these countries aim to create various solutions related with the CE transition in FSCs. They are very valuable for knowledge transfer to undeveloped nations.

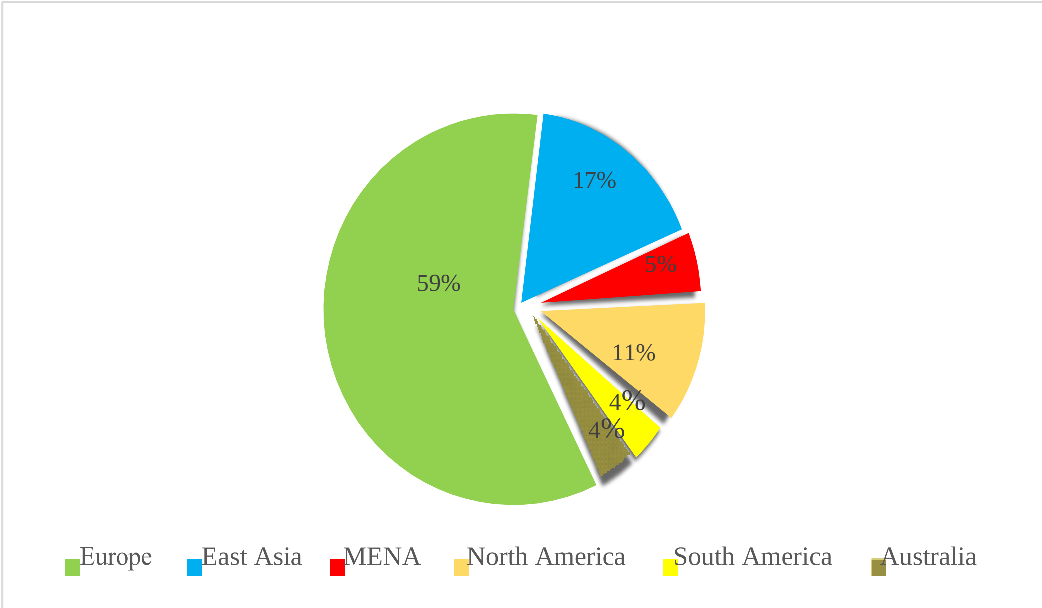

Figure 5. Articles by continents and regions.

As noticed in Figure 6, it can be included that the interaction between the methods and the principles of CE, which are "reduce" and "rethink," is the most applied CE activity in those studies that are mainly for systematic literature review, and case study. Besides, the "reduce" dimension primarily utilizes different research techniques listed as shown in the figure since the primary driver of CE is reducing food waste to decrease negative impacts on environmental impacts by redesigning and rethinking supply chain processes.

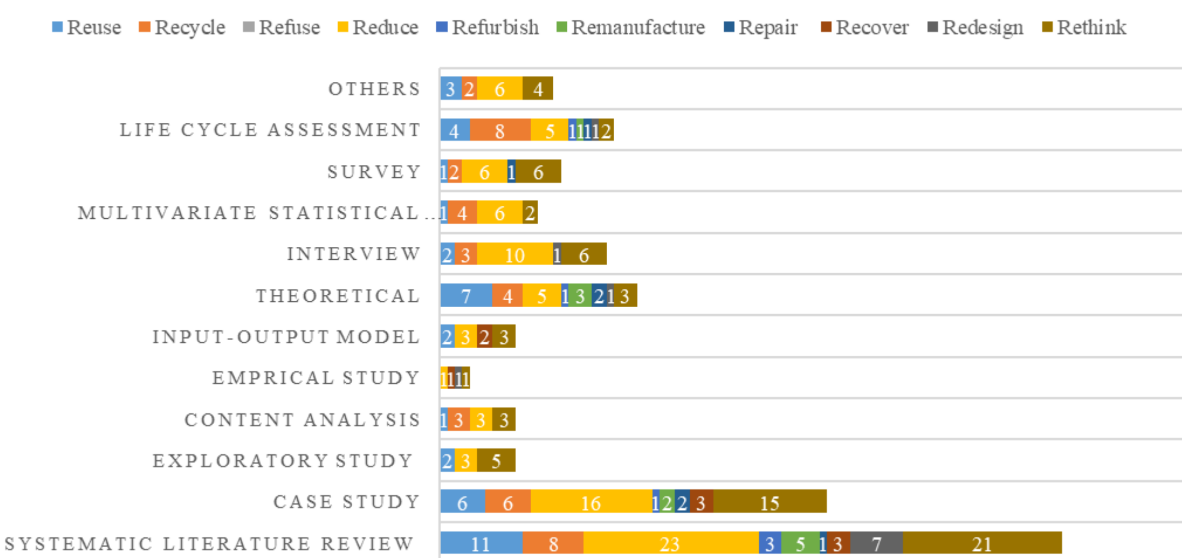

Figure 6. Interaction between methods and CE dimensions.

The following graph in Figure 7 demonstrates that the relationship between the focus area and the top principles of CE, "reduce" and "rethink" are the most applied CE activity in those mainly for industry and policymakers. However, the different principles play similar roles in academia-focused articles. Studies under consideration mostly suggested solutions to industry and practitioners.

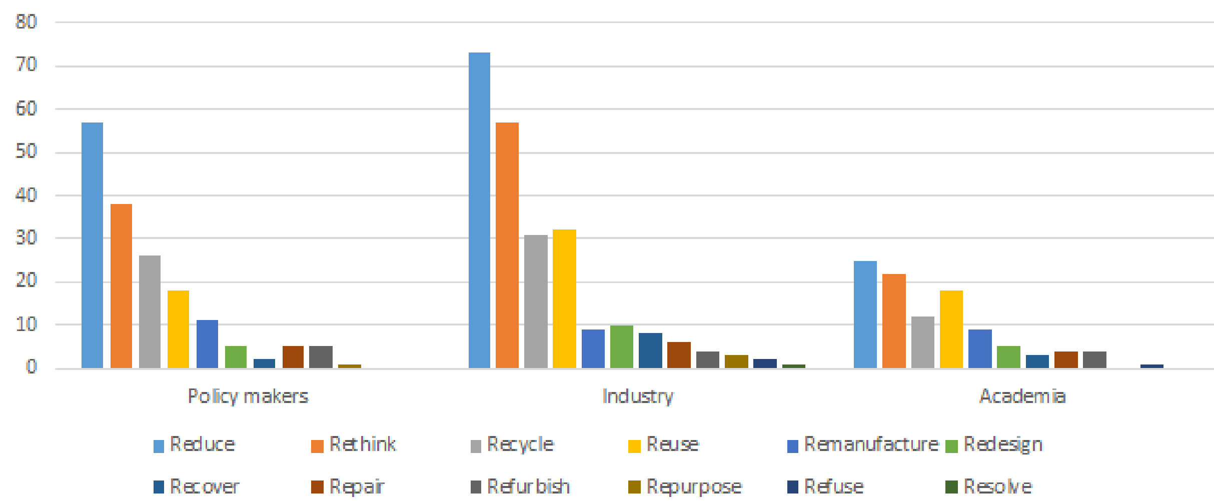

Figure 7. Interaction between the CE principles and focus area.

Table 2 indicates the drivers that have a significant motivation of CE on FSCs. As mentioned in table 2, drivers were categorized into five categories, which are: "Economic & Managerial," "Technological," Environmental," "Supply Chain Management," and "Regulatory & Social," respectively, with 22 sub-drivers. Achieving competitive advantage and improving the company's image by providing customer satisfaction is one of the company's main objectives. The success of these actors requires both a holistic approach and specialized human resources management. These motivations are illustrated by an "Economic & Managerial" classification. To adopt the transition to a CE, the" Environmental" impact of the implementation of CE has been categorized as another significant group that proposes environmental directives to protect the environment's efficient use of resources, energy, and materials. CE ensures that supply chain risks by reducing material dependency; digital technologies aim to improve efficiency and provide flexibility on products and throughout the processes. Thus, a value-added chain can be created by providing value-added processes throughout the entire FSCs. All these motivations of CE are discussed under one of the sub-drivers titled "Supply Chain Management." CE perspectives should be supported by innovation and digitalization tools to implement circularity effectively. The integration of digitalization and CE can also activate or motivate the drivers by providing various improvements to gain competitive advantages. Therefore, the "Technology" dimension is one of the main categories. Besides, responsibilities and legal regulations regarding with the social and environmental aspects of sustainability are the key drivers to motivate the applying CE strategies in the whole supply chain. Enhancing awareness of sustainable economies and societies is another important sub-driver to achieve and adopt CE principles. Therefore the main driver that covers legal and social responsibilities is classified as "Regulatory & Social."

To better understand the interaction CE dimension between stages of supply chain and sub-food sectors and CE and the intersection of the sub-sectors and supply chain stages are discussed in Figures 8, 9, and 10.

Table 2. Potential drivers of CE in the context of FSCs.

Drivers	Sub-drivers	Author(s)
Economic & Managerial	(D1) Enhancing efficiency to reduce costs	Fadhel et al. (2017), Sposato et al. (2017), De Mattos and De Albuquerque (2018), Laso et al. (2018), Bottani et al. (2019), Howard et al. (2019), Katare et al. (2019), Slorach et al. (2020).
	(D2) Improving the firm image	Garcés-Ayerbe et al. (2019)
	(D3) Ensuring customer satisfaction	Loke and Leung (2015), Richter and Bokelmann (2017), Bravi et al. (2020), Moreno et al. (2020).
	(D4) Achieving competitive advantage	Filimonau et al. (2019), Tura et al. (2019), Meghana and Shastri (2020).
	(D5) Implementing systems approach	Halloran et al. (2014), Kirwan et al. (2017), Horton et al. (2019), Avraamidou et al. (2020), Ghinoi et al. (2020).
	(D6) Increasing knowledge level and diversify skill of workers	Walker et al. (2014), Winans et al. (2017), De Angelis et al. (2018), Homrich et al. (2018), Liaskos et al. (2019), Russell et al. (2020), Sehnem et al. (2019).
Environmental	(D7) Reducing the negative impact of the company's activities on the environment	Miliute -Plepiene and Plepys (2015), Fletcher and Dunk (2018), Grimm and Wösten (2018), Petit-Boix and Leipold (2018), Scherhaufer et al. (2018), Cakar et al. (2020), Guven et al. (2019), Hart et al. (2019), Lemaire and Limbourg (2019), Mattila et al. (2019), Papargyropoulou et al. (2019), Colley et al. (2020), Ghisellini and Ulgiati (2020), Kayikci et al. (2020), Read et al. (2020), Teigiserova et al. (2020).
	(D8) Increasing the efficiency of materials and energy use	Verghese et al. (2015), Batista et al. (2019).
	(D9) Efficient use of resources	Kaipia et al. (2013), Pagotto and Halog (2016), Rizos et al. (2016), Merli et al. (2018), Paes et al. (2019), Slorach et al. (2019), Urrutia et al. (2019), Zhu et al. (2019), Derqui et al. (2020), Krishnan et al. (2020), Udugama et al. (2020).
	(D10)Reducing the environmental footprint of the products	Mondéjar-Jiménez et al. (2016), Richter and Bokelmann (2017), Liu et al. (2018), Leverenz et al. (2019), Munesue and Masui (2019), Galford et al. (2020), Muhammad and Rosentrater (2020).
Supply chain management	(D11) Decreasing raw material dependency	Faucher and Isabelle (2016), Fami et al. (2019), Zamri et al. (2020).
	(D12) Minimizing the risks related to the supply chain	Genovese et al. (2017), Govindan and Hasanagic (2018).
	(D13) Improving productivity using smart decision tool and models	de Sousa Jabbour et al. (2018), Belaud et al. (2019), Ciulli et al. (2020), Kouhizadeh et al. (2020), Machado et al. (2020).
	(D14) Increasing flexibility of processes and products	Eggleston and Lima (2015), Moncada and Aristizabal (2016), Davenport et al. (2019), Vinck et al. (2019), Bala et al. (2020), D'Agostin et al. (2020), Sehnem et al. (2020).
	(D15) Value chain engagement	Parfitt et al. (2010), Jurgilevich et al. (2016), Matharu et al. (2016), Noya et al. (2017), Vlajic et al. (2018), Chauhan and Singh (2019), Sadhukhan et al. (2020).
Technological	(D16) Strengthen existing production and exploring new systems	Genovese et al. (2017), de Hooge et al. (2018), de la Caba et al. (2019), Fidelis et al. (2019), Kerdlap et al. (2019), Kerin and Pham (2019), Liegeard and Manning (2020).
	(D17) Involvement in R&D activities	Cecchi and Cavinato (2019), Rivera et al. (2019).
	(D18) The development of eco-innovations	De Jesus and Mendonça (2018), Kiefer et al. (2019).
	(D19)Availability of adequate technological knowledge	Awasthi et al. (2020), Rosa et al. (2020).
Regulatory & Social	(D20) Waste management complies with legal requirement	Berardi et al. (2019), Busetti. (2019), Fedotkina et al. (2019), Vaneeckhaute and Fazli (2020).
	(D21) Estimating legal/social responsibilities in the future	Murray et al. (2017), Mak et al. (2020).
	(D22) Enhancing awareness of sustainable economies and societies	Smith et al. (2008), Borrello et al. (2017), Geissdoerfer et al. (2017), Ponis et al. (2017), Sgarbossa and Russo (2017), Alhola et al. (2019), Avdiushchenko and Zając (2019), Baig et al. (2019), Boulet et al. (2019), Fassio and Minotti (2019), Fux (2019), Gollnhofer et al. (2019), Kiss et al. (2019), Lemaire and Limbourg (2019), Mu'azu et al. (2019), Pearson and Amarakoon (2019), Pai et al. (2019), Sirola et al. (2019), Coderoni and Perito (2020), Derqui et al. (2020), Prescott et al. (2020), Salvador et al. (2020).

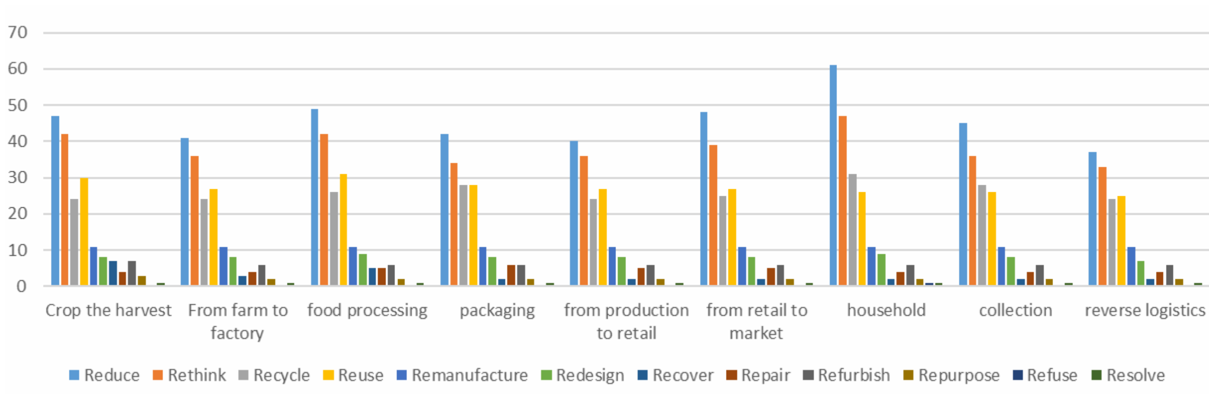

Figure 8. The intersection of stages of the supply chain and CE dimension.

According to Figure 8, most of the articles are focused mainly on "reduce," "rethink," "reuse," and "recycle," considering the dimensions of CE. These dimensions equally prioritize different supply chain stages, with a focus on the household stage, as most of the articles covered are from developed countries. Thus, the focus on the household stage for CE activities is noteworthy in these countries. Still, it can be said that developing countries also should focus on the beginning of FSCs, such as farm level, when implementing CE activities.

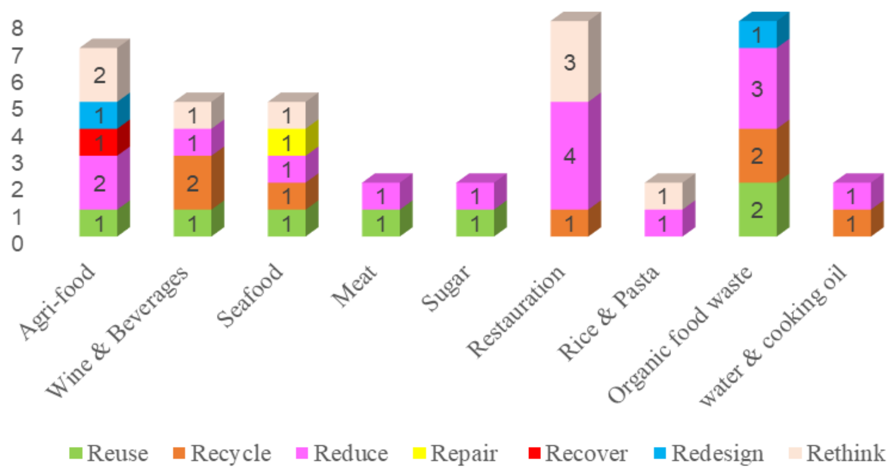

Figure 9. The intersection of sub-sectors and CE dimension.

Based on Figure 9, it is concluded that articles are mainly considered "reduce" and "rethink" for the restoration and agri-food sectors. Meat and sugar sectors focus on CE concepts: "reduce" and "reuse." While rice and pasta industries are dealt with "rethink" and "reduce" dimensions, water and cooking oil are tackled with "recycle" and "reduce" dimensions. The wine and beverages industry mainly focused "recycle" dimension. The main CE concepts for organic food waste are "reduce," "recycle," and "reuse."

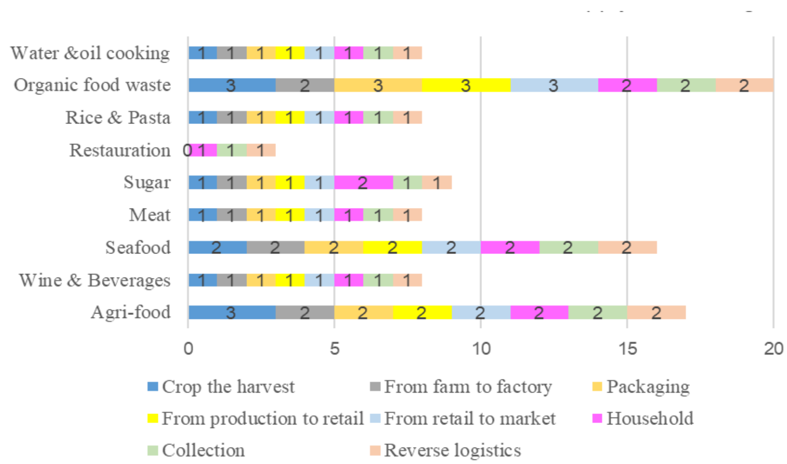

Figure 10. The intersection of sub-sectors and supply chain stages.

Figure 11. The intersection of sub-drivers of FSCs and CE dimensions.

Based on Figure 10, it is determined that while crop the harvest stages is critical stages for organic food waste, agri-food, seafood industry, "household," "collection," and "reverse logistics" steps are essential for restoration sectors. Since this sector mainly focuses on after-production stages to end customers. Transportation and logistics stages need to be considered critical for all industries. All stages are necessary for the meat, sugar, wine, and beverages sectors.

As shown in Figure 11, while improving the firm image is only motivated by the "rethink" dimension; achieving competitive advantages is also stimulated by the "reduce" dimension. Besides, legal/social responsibilities and awareness of society are mainly dominated by "reuse," "reduce," "recycle," and "rethink." "Reuse," "reduce," "recover," and "rethink" dimensions are considered for implementing the system approach to give insight into holistic viewpoints to FSCs. Whereas the development of eco-innovations is stimulated by "reuse," "remanufacturing," and "rethink" dimensions; involvement in R&D activities is motivated by "reuse," "recover," and "repurpose." However, the remain of sub-drivers is encouraged by almost all CE dimensions.

Figure 12. Interaction between sub-drivers and supply chain stages.

Based on Figure 12, it is concluded that almost all stages of FSCs are motivated by various sub-drivers such as enhancing efficiency to reduce costs, improving firm image, implementing system approach, increasing knowledge level and diversify skill of workers, decreasing the negative impact of the company's activities on the environment, efficient use of resources, reducing the environmental footprint of the products, decreasing raw material dependency, minimizing the risks related to the supply chain, improving productivity using smart decision tool and models, increasing flexibility of processes and products, value chain engagement, strengthen existing production and exploring new systems, the development of eco-innovations, availability of adequate technological knowledge, waste management complies with legal requirements, estimating legal responsibilities in the future, enhancing awareness of sustainable economies and societies. From retail to market, the household and collection stage of FSCs is essential for increasing satisfaction.

Figure 13 indicates the relationships between CE dimensions and digital technologies. Continuously tracking systems through Blockchain technologies reduce waste in the FSCs by stimulating "reuse" and "recycle" in the system. Various sensor systems such as IoT (Internet of Things), RFID (Radio-Frequency Identification), CPS (Cyber-Physical Systems), Nanotechnologies, and Barcodes are critical to increase food safety and prevente food spoilage that creates food waste in the supply chain (Atkins et al., 2018; Akinade et al., 2019). Through these systems, CE can be achieved in the FSCs by increasing the "reuse", "reduce", "recycle", "remanufacturing", and "repair" of the food industry (Jabbour et al., 2020). Machine learning and AI provide increased processing efficiency and reduced food waste. Besides, AI (Artificial Intelligence), BDA (Big Data Analytics), and Machine Learning enable better match supply with demand to manage inventory effectively by reducing overstocking (Ranta et al., 2018; Nayal et al., 2021). "Repurpose", "rethink" and "redesign" the concept of CE can be achieved with the two significant technology (Cherrafi et al., 2022). CC (Cloud Computing) and AGV (Automated Guided Vehicles) helps to ensure real-time information in the supply chain and aims to monitor, predict, optimize and increase traceability by promoting recovery, recycling, and remanufacturing in FSCs (Ormazabal et al., 2018; Abideen et al., 2021b). 3DP (Three Dimensional Printing) is the most crucial promising technology in the FSCs by increasing personalized food manufacturing and providing on-demand food production (Okorie et al., 2018; Lerman et al., 2022). Thus, this technology can be useful for increasing CE in the FSCs by promoting reuse and recycling, repair in the food industry (De Angelis et al., 2018; Bressanelli et al., 2022).

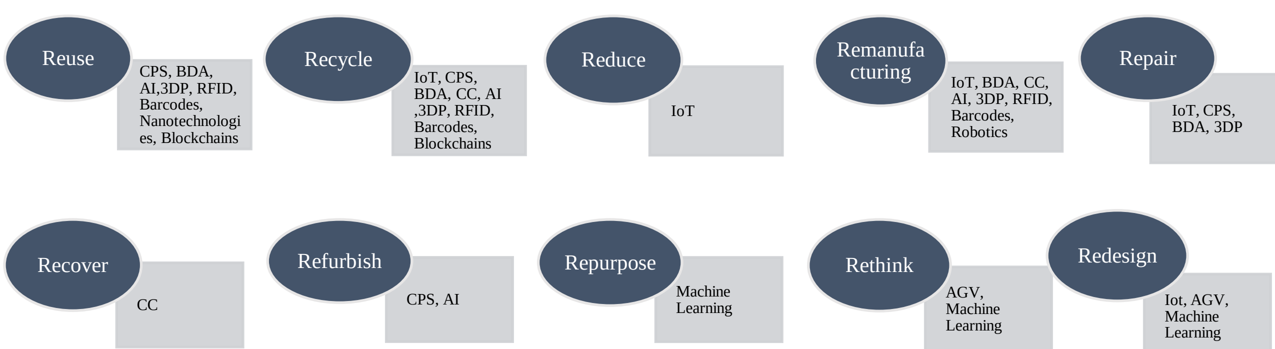

Figure 13. Relationships between CE dimensions and digital technologies.

Table 3 describes sub-drivers that are stimulated by various digital technologies. Machine learning provides increased "processing efficiency" and ensures a better match of supply with demand; thus, it is motivated to "enhance efficiency", increasing "customer satisfaction" to achieve a competitive advantage (Meghana and Shastri, 2020). Another important driver of CE in FSCs is "implementing a systems approach" to give a deep insight into the whole supply chain. This driver needs to be stimulated by different technologies such as IoT, AGV, Machine Learning, CPS, BDA, CC, AI,3DP, RFID, Barcodes, and Blockchains (Avraamidou et al., 2020; Ghinoi et al., 2020). BDA, Machine learning, and sensor technologies are very crucial in providing real-time data entire supply chain for "ensuring effective supply chain management", which is one of the essential main drivers of CE in FSCs (Govindan and Hasanagic, 2018; Machado et al., 2020; Abiden et al., 2021a; Mahroof et al., 2021). Drivers of CE related to the environmental dimensions can motivate by efficiently using the material, reducing negative footprint in the supply chain, and "decreasing negative impacts on the environment" (Ada et al., 2021). Therefore, 3DP technology can stimulate reaching these purposes in the FSCs (Teigiserova et al., 2020; Mahroof et al., 2022; Cherrafi et al., 2022). Drivers related to "the strength of existing production and exploring new systems", "increased involvement in R&D activities", "enhancing the development of eco-innovations", and "providing availability of adequate technological knowledge" can be motivated by the various technologies such as IoT, CPS, BDA, AI, 3DP, RFID, Barcodes, Robotics, Blockchains, AGV, Machine Learning, Cloud Computing (de la Caba et al., 2019; Liegeard and Manning, 2020; Abiden et al., 2021b). Adopting different digital technologies (IoT, AGV, Machine Learning, CPS, AI, BDA,3DP, etc.) should be supported by the government to conduct "waste management complies with a legal requirement", "estimate legal responsibilities in the future", "enhance awareness of sustainable economies and societies" (Prescott et al., 2020; Abideen et al., 2021a; Mahroof et al., 2022). Table 3 summarizes various CE sub-drivers in FSCs stimulated by various digital technologies.

Thus, Figure 14 presents the proposed Industry 4.0 technologies corresponding to each CE sub-driver of FSCs.

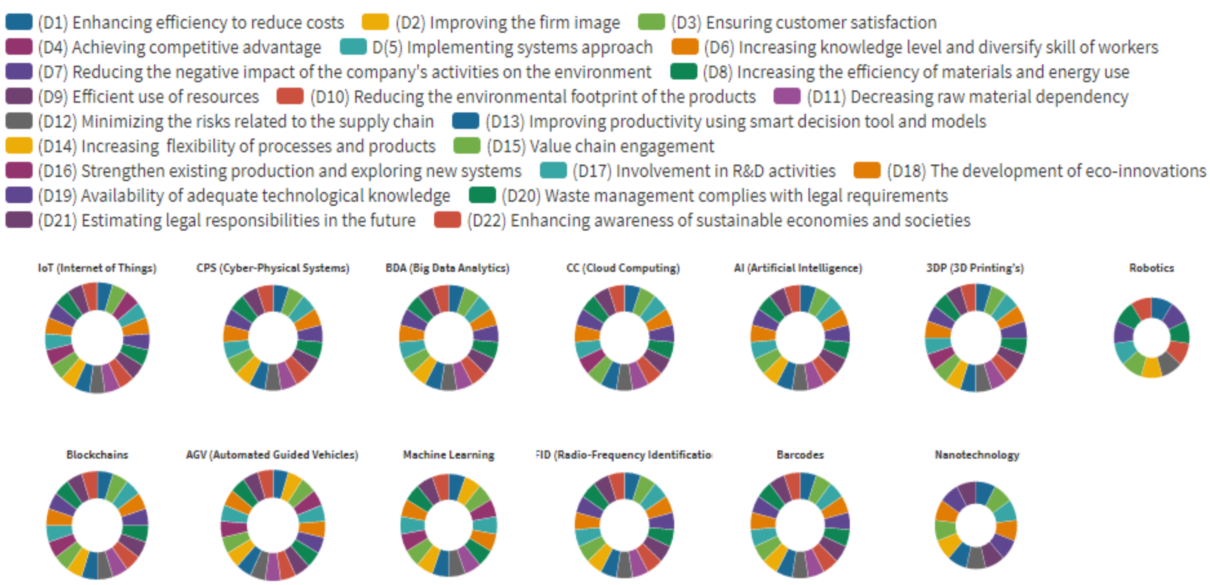

Figure 14. Sub-drivers of FSCs and industry 4.0 technologies.

The drivers are required to be activated and stimulated for transition from linear to CE within FSCs. Thus, the managers of the FSCs desiring to implement CE may have used these technologies to stimulate each driver. The proposed figure may answer the question of the right technology to hire, enabling the companies to decide on the necessary investment.

Table 3. Sub-drivers that are stimulated by various digital technologies.

Main Drivers	Sub-Drivers	CE Dimensions	Industry 4.0	References
Economic & Managerial	(D1) Enhancing efficiency through reducing costs	Reuse, Recycle, Reduce, Rethink, Remanufacturing, Redesign, Repair	IoT, CPS, BDA, AI, 3DP, RFID, Barcodes, Robotics, Blockchains, AGV, machine learning	Slorach et al. (2019).
	(D2) Improving the firm image	Rethink	AGV, Machine Learning	Garcés-Ayerbe et al. (2019), Cherrafi et al. (2022).
	(D3) Increasing customer satisfaction	Reduce, Rethink, Reuse, Recycle	Iot, AGV, Machine Learning, CPS, AI, CC, CPS, BDA, AI, 3DP, RFID, Barcodes, Blockchains	Bravi et al. (2020), Moreno et al. (2020), Cherrafi et al. (2022).
	(D4) Achieving competitive advantage	Reduce, Rethink	Iot, AGV, Machine Learning	Filimonau et al. (2019), Meghana and Shastri (2020), Lerman et al. (2022).
	(D5) Implementing systems approach	Rethink, Reduce, Recover, Reuse	Iot, AGV, Machine Learning, CPS, BDA, CC, AI,3DP, RFID, Barcodes, Blockchains	Avraamidou et al. (2020), Ghinoi et al. (2020).
	(D6) Increasing knowledge level and diversify skill of workers	Remanufacturing, Rethink, Repurpose, Reduce, Reuse, Recycle, Repair, Refurbish	IoT, BDA AI, CPS, 3DP, RFID, Barcodes, Robotics, Nanotechnology, Machine Learning	Russell et al. (2019), Sehnem et al. (2019).
Environmental	(D7) Reducing the negative impact of the company's activities on the environment	Reuse, Recycle, Reduce, Rethink, Recover, Refurbish, Repurposes, Remanufacture	IoT, CPS, BDA, CC, AI, 3DP, RFID, Barcodes, Robotics, Blockchains, AGV, machine learning	Ghisellini and Ulgiati (2020), Teigiserova et al. (2020).
	(D8) Increasing the efficiency of materials and energy use	Rethink, Reduce, Reuse	IoT, CPS, BDA, AI,3DP, RFID, Barcodes, Blockchains, AGV, machine learning	Batista et al. (2019), Mahroof et al. (2022).
	(D9) Efficient use of resources	Reuse, Recycle, Reduce, Rethink, Recover, Repair, Remanufacturing, Redesign, Refurbish	IoT, CPS, BDA, CC, AI, 3DP, RFID, Barcodes, robotics, Blockchains, AGV, machine learning	Slorach et al. (2019), Krishnan et al. (2020), Cherrafi et al. (2022).
	(D10) Reducing the environmental footprint of the products	Reduce, Recycle, Rethink, Redesign	IoT, CPS, BDA, AI, 3DP, RFID, Barcodes, Cloud Computing, Blockchains, AGV, machine learning	Muhammad and Rosentrater (2020), Mahroof et al. (2022).
Supply chain management	(D11) Decreasing raw material dependency	Reuse, Recycle, Repair, Rethink, Reduce, Remanufacture	IoT, CPS, BDA, AI, 3DP, RFID, Barcodes, CC, Blockchains, Robotics, Nanotechnology, AGV, Machine Learning	Fami et al. (2019), Lerman et al. (2022).
	(D12) Minimizing the risks related to the supply chain	Reuse, Recycle, Repair, Rethink, Reduce, Redesign, Recover	IoT, CPS, BDA, CC, AI, 3DP, AGV, Blockchains, machine learning	Govindan and Hasanagic (2018), Joshi and Sharma (2021), Lerman et al. (2022).
	(D13) Improving productivity using smart decision tool and models	Reuse, Recycle, Repair, Rethink, Reduce, Resolve, Remanufacture, Redesign	IoT, CPS, BDA AI, 3DP, RFID, Barcodes, Robotics, Nanotechnology, AGV, Machine Learning	Belaud et al. (2019), Machado et al. (2020).
	(D14) Increasing flexibility of processes and products	Rethink, Reduce, Reuse, Recycle	IoT, BDA, AI, 3DP, RFID, Barcodes, Robotics, Nanotechnology, CPS, AGV, Machine Learning	Sehnem et al. (2019), Vinck et al. (2019), D'Agostin et al. (2020), Mahroof et al. (2022).

Table 3 continued…

	(D15) Value chain engagement	Reuse, Recycle, Rethink, Reduce, Recover, Remanufacture, Redesign, Refurbish	CPS, BDA, AI, 3DP, RFID, Barcodes, Robotics, Blockchains, CC, Iot, AGV, Machine Learning	Noya et al. (2017), Abiden et al. (2021a).
Technological	(D16) Strengthen existing production and exploring new systems	Rethink, Reuse, Recycle, Reduce, Redesign, Repair, Refurbish, Repurposes	IoT, CPS, AI, 3DP, BDA, Blockchains, Iot, AGV, Machine Learning	de la Caba et al. (2019), Liegeard and Manning (2020), Abiden et al. (2021a).
	(D17) Involvement in R&D activities	Recover, Reuse, Repurpose	CPS, BDA, CC, AI, 3DP, RFID, Barcodes, Blockchains, Robotics, Nanotechnology, Machine learning	Cecchi and Cavinato (2019), Rivera et al. (2019).
	(D18) The development of eco-innovations	Remanufacture, Reuse, Rethink	IoT, CPS, BDA, AI,3DP, RFID, Barcodes, Robotics, Blockchains, AGV, Machine Learning, Cloud Computing	Kiefer et al. (2019), Joshi and Sharma (2022).
	(D19) Availability of adequate technological knowledge	Remanufacturing, Recycle, Reuse, Reduce	IoT, BDA, AI, 3DP, RFID, Barcodes, Robotics, Nanotechnology, CPS	Awasthi t al. (2020), Rosa et al. (2020).
Regulatory & Social	(D20) Waste management complies with legal requirements	Reduce, Reuse, Rethink, Remanufacture	IoT, CPS, BDA, AI,3DP, RFID, Barcodes, Robotics, Blockchains, Machine Learning, AGV	Vaneeckhaute and Fazli (2020), Abideen et al. (2021b).
	(D21) Estimating legal responsibilities in the future	Rethink, Reduce, Reuse, Recycle	IoT, AGV, Machine Learning, CPS, BDA, AI,3DP, RFID, Barcodes, Blockchains	Mak et al. (2020), Mahroof et al. (2022).
	(D22) Enhancing awareness of sustainable economies and societies	Reuse, Recycle, Reduce, Rethink, Redesign, Repair, Repurposes	IoT, AGV, Machine Learning, CPS, AI, BDA,3DP	Pai and Zhang (2019), Prescott et al. (2020).

5. Discussions and Implications

Improving the firm image, ensuring customer satisfaction, achieving competitive advantage, implementing a systems approach, value chain engagement, strengthen existing production, and exploring new systems can be achieved through the systems thinking approach. Due to the complexity inherent in FSCs, it is necessary to see the big picture and handle processes as a whole. However, the complexity of the FSCs enforces digital technologies to embrace the whole system and consider the interactions among stakeholders. Therefore, industry 4.0 technologies such as AGV, machine learning, and BDA should be used in understanding the system, analyzing the processes, and developing the designs of the products. With these technologies, processes should be investigated, and developed based on a rethink of the concept of CE at the design stage of the products. Through the systems approach, which offers a holistic perspective on the design of products and processes, the processes can be viewed as a whole. Then the problematic points of the processes can be clarified. Hence, the implications are structured based on sub-drivers in five categories: process and system approach, based on stakeholders' theories, supply chain management, eco-innovation, and social impact. As a theoretical implication, this paper provides a holistic perspective by handling CE concepts with the different aspects of the FSCs.

Sub-drivers discussed in Table 2 can be activated by using different industry 4.0 technologies such as IoT, CPS, BDA, CC, AI, 3DP, Robotics, Blockchains, AGV, Machine Learning, RFID, Barcodes, Nanotechnology. Thus, CE dimensions can be improved by using industry 4.0 technologies.

Machine learning is mainly used for various process optimization, system analysis, monitoring, and control of processes (Susto et al., 2015). In addition, machine learning shall be used to determine the cause of problems in production processes in the FSCs where complex production environments exist (Wuest et al., 2016). Machine learning should be considered an essential tool, especially in complex production processes such as FSCs to solve multi-dimensional problems and increase the image of the company by gaining a competitive advantage, strengthening and developing production processes as an industry 4.0 technology with the capability to establish a value chain (Abdul-Hamid et al., 2020). Minimizing the adverse effects of the company's activities on the environment, increasing the efficiency of materials and energy use, efficient usage of resources, minimizing the environmental footprint of the products (Ilić and Nikolić, 2016), enhancing efficiency to reduce costs can be activated via industry 4.0 technologies which are Blockchains, big data, and 3DP (Jabbour et al., 2020).

These sub-drivers are aimed to reduce the negative impact on the environment by adapting the CE principles in FSCs, which include various processes from farm to fork. The transformation of a production system involves the participation of various stakeholders and actors, including suppliers, producers, distributors, retailers, and customers. To deal with these multi-stakeholder structures of FSCs, using blockchain technologies is to increase FSCs reliability and ensure data sharing effectively (Khan et al., 2022). With this technology, transparency of product, tracking of the whole supply chain, and traceability will be ensured throughout the process from producers to end-users. Besides, 3DP aims to develop technologies that focus on recycled materials or reusing products/materials, especially in the design stage of products, to promote the redesign of products or components. Companies can improve their CE manner by optimizing parameters related to the developed product in the supply chain's initial phase. Another important technology that encourage the CE to reduce the negative impact on the environment is BDA technologies. The FSCs, which have a complex and multi-stakeholder structure, require analysis, and innovative approaches for data management. As mentioned before, FSCs include complex and multi-stakeholder structure (Jakhar et al., 2019; Nayal et al., 2021). Therefore, supply chain performance criteria have been changed because of the adoption of CE principles. CE principles turn traditional supply chains with linear structures into circular systems. Thus, the increase in both the quantity and quality of production processes and supply chain stakeholders can only be managed effectively by adapting industry 4.0 technologies (Yadav et al., 2020). Decreasing raw material dependency, minimizing the risks related to the supply chain, improving productivity using smart decision tools and models, and increasing flexibility of processes and products can be motivated through BDA, robotics, and barcode technologies (Harding et al., 2006; Sharma et al., 2019). Robotics and 3DP have been suggested to reduce production costs for the product design, production, and remanufacturing processes and to achieve more sustainable operations (González-Sánchez et al., 2020).

Involvement in R&D activities, developing eco-innovations, and providing adequate technological knowledge are essential sub-drivers to achieve a more sustainable and innovative supply chain. Practical training that is encouraged by policymakers and government is critical for improving R&D capabilities in this transition. Initially, while innovation management is just one of the most substantial criteria in supply chains, integrating innovative designs with environmentally friendly structures has become a more significant issue for FSCs due to the adaptation of CE principles. Therefore, the design stage should consider various CE principles such as reuse, recycling, and remanufacturing. Products should be designed according to the circular processes that can implement closed-loop supply chain principles from the design stage to perform efficient and effective end-of-life activities such as disassembly operations. To achieve these purposes, industry 4.0 technologies such as 3DP and Nanotechnology should be used to create faster, more innovative designs and environmentally-friendly products. Nowadays, the nature of the supply chain is transformed according to circularity. Because of that, the performance criteria have been changed, which causes managers to deal with them more effectively. Since producing innovative and environmental-friendly products in high volume within a limited period is evitable to achieve competitive advantages, the supply chain performance criteria have been changed. Moreover, achieving these criteria require disseminating and sharing the information obtained from the whole process and all stakeholders. By utilizing blockchain technology, the FSCs can efficiently collect, manage, and share data among all stakeholders, ensuring complete transparency. The integration of Industry 4.0 technologies like blockchain can lead to the creation of environmentally sustainable and innovative products. To fully harness the potential of these technologies, it's crucial for managers, policymakers, and governments to work together in developing effective infrastructure and implementing supportive strategies and policies that encourage the widespread adoption of digital technologies in the food industry.

To achieve sustainable production processes, the environmental, economic dimension, and the analysis of social impacts should be carried out effectively via digital technologies (Esmaeilian et al., 2020) such as blockchain and machine learning. It is noteworthy that government regulations directly influence supply chain processes (Abideen et al., 2021a). Therefore, redesign of production processes and supply chain networks should be implemented by considering new governmental regulations and policies from CE perspectives. While analyzing legal structures and social aspects of sustainability can be accomplished with machine learning technologies, FSCs should be traced using blockchain technologies to provide traceability and transparency of information in the entire supply chain (Ciccullo et al., 2021). Similarly, waste management complies with legal requirements, estimating legal responsibilities in the future, and enhancing awareness of sustainable economies and societies are activated through suggested Industry 4.0 technologies.

6. Conclusions

CE has gained importance for the government, policymakers, and practitioners, recently. The primary purpose of CE is to reduce resources, waste, and emissions by creating a supply chain that transitions from environmentally harmless from production to consumption. The CE is an approach that offers a perspective for the transition from linear economies to circular economies by holistically addressing economic growth with sustainable economic, environmental, and social development. Therefore, it is significant to investigate drivers of CE dimensions. In addition, food waste has become a global problem for both developed and developing countries in achieving sustainability and food security. CE dimensions need to be re-designed by integrating them into FSCs to tackle this global problem. Thus, this paper mainly focuses on drivers of CE in FSCs by analyzing how CE dimensions are activated in FSCs. Specifically, the main contribution of this study is to describe both drivers and sub-drivers of CE in FSCs. It reveals the implementation of CE in FSCs by proposing implications within digitalization that can be considered a guide to comprehend the benefits of CE.

A systematic literature review on CE perspectives in FSCs was conducted using 137 papers from Scopus and WOS. This study entails contributions by suggesting main and sub-drivers at the interaction of CE principles and FSCs stages. The findings of the study propose potential drivers that are categorized by main and sub-drivers of CE in the FSCs. The main drivers are Economic & Managerial, Environmental, Technological, Supply Chain Management, Regulatory and Social. Digital technologies have been discussed to contribute to the application of CE in FSCs. The results of this study propose different suggestions on how and which industry 4.0 technologies, such as IoT, Nanotechnology, CPS, CC, AI, BDA, 3DP, Robotics, Blockchains, AGV, Machine Learning, RFID, Barcodes, can be considered for the adaptation of CE dimensions in FSCs. Companies should integrate digital technologies into their processes to increase productivity, improve quality, gain competitiveness, and create environmentally friendly products and flexible production systems. Besides, this study contributes to the literature investigating drivers of CE in the FSCs with digital technologies. This paper also highlights the aspects of the intersection of CE and digital technologies to stimulate drivers. The role of Industry 4.0 in adapting CE in FSCs has been analyzed in this paper. Moreover, this study discusses the various benefits of industry 4.0 applications to policymakers and industry.

As a limitation of the study, the review is conducted using academic journals and conference articles in English between 2008-2020. Thus, other languages and publications are apart from this study. This study focuses on the

9R concepts and other CE dimensions that can also be critical for the food industry. Different research items such as research reports and books can be added as future work. Different solutions can be developed by increasing other industry 4.0 techniques and CE dimensions. Drivers of CE in FSCs can be matched with various specific digital technologies.

Conflict of Interest
The authors confirm that there is no conflict of interest to declare for this publication.

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