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A fuzzy TOPSIS model for selecting digital technologies in circular supply chains

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ABSTRACT

Several digital technologies are available to facilitate the transition toward a circular supply chain infrastructure. Small-Medium Enterprises (SMEs) should assess their readiness and measure their performance to select the most appropriate digital technology. This study explores how well-established digital technologies such as Cyber-Physical Systems (CPS), the Internet of Things (IoT), Cloud Manufacturing (CM), and Big Data Analytics (BDA) impact circular supply chain infrastructure in SMEs. Questionnaires have been distributed to collect employees' preferences concerning the circular supply chain management criteria (profit, innovation, sustainability, and optimization). The responses have been organized into three clusters using Principal Component Analysis (PCA). A fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) technique is adopted to evaluate these technologies since it constitutes a reliable managerial tool when vagueness impacts the smooth operation of the supply chain. Results indicate the ranking order of the investigated digital technologies (CPS>IoT>CM>BDA) as well as the circular benefits and the supply chain attributes imparted upon implementing these technologies. Such benefits and attributes are provided to assess the impact of these digital technologies on a circular economy. Lastly, the perspective of the selection process affected by other factors, such as the enterprise's extroversion level and its internal structure, are discussed.

1. Introduction

Natural resource scarcity remains a complex ongoing issue influencing how enterprises do business. The existing business economic model is perceived to be linear, while at the same time, it poses a threat to the selfless provision of resources deriving from the natural world [1]. On that basis, the transition to a circular economy (CE) has emerged as an attempt to provide sustainable operations and eco-friendly business consciousness [2,3]. Drawing on the transitional period towards circularity, supply chain management (SCM) has been influenced by the rapid spread of circular activities leading to the formation of circular supply chains [4,5].

Several business models have been adopted to foster the transition towards circularity. In particular, closed-loop supply chains constitute the epitome of the circular supply chain management (CSCM) [6,7]. Closing the loop is essential because it enables companies to ensure zero waste in the landfill [8,9]. Additionally, collaborative partnerships among supply chain members set solid grounds for circularity since all echelons within the supply chain network cooperate in order to achieve sustainability and support the zero-waste initiative [6].

The circular flow of materials and circular supply chain infrastructure can be reached by leveraging the most prominent technological means. More specifically, the concept of Industry 4.0 is widely known and embodies several digital technologies [3,10]. For instance, the Internet of Things (IoT), cyber-physical systems (CPS), cloud manufacturing (CM) and big data analytics (BDA) constitute examples of unique digital technologies according to a growing body of literature [11–13]. As explained by Bibby and Dehe [14] such digital technologies offer substantial benefits to achieve circularity in supply chains.

Furthermore, organisations need to demonstrate their readiness to evaluate and efficiently select which of the existing digital technologies are sufficient towards the transition to CSCM. Taking into account

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Pangaribuan and Beniyanto's [15] study, the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method has been validated as the appropriate multi-criteria decision-making (MCDM) methodology for pinpointing the ideal point of the considered alternatives. On the basis of this statement, TOPSIS offers a straightforward and intuitive approach by considering both the proximity to the best option and the remoteness from the worst option, providing a balanced view of the alternatives. Moreover, it has a solid theoretical foundation and has been successfully applied in various domains (e.g., [16]), demonstrating its robustness and reliability. Chen [16] proposed a revised version of the conventional TOPSIS method, known as the fuzzy TOPSIS methodology. Fuzzy TOPSIS has been developed to facilitate the selection of a range of alternatives concerning different criteria, especially in circumstances where uncertainty and vagueness tremendously impacts the smooth operation of the supply chain decision-making processes [17]. Fuzzy TOPSIS extends the traditional TOPSIS method by incorporating fuzzy logic, which is particularly beneficial when dealing with imprecise or ambiguous data, a common occurrence in real-world decision-making scenarios. It provides a more realistic representation of decision problems by accommodating subjective judgments and linguistic variables [19]. Fuzzy TOPSIS has been applied to address different supply chain challenges. For instance, Chen [16] employed fuzzy TOPSIS for supplier selection, while Kannan [18] utilised this method to identify green suppliers according to their environment-friendly practices in the SCM context. Husain [19] used the fuzzy TOPSIS approach to analyse 11 business models towards the implementation of the CE. Hajiaghaei-Keshteli [20] have recently introduced a Pythagorean fuzzy TOPSIS approach for green supplier selection within the food industry.

Although various methodological frameworks involving multi-criteria decision-making tools have been developed to facilitate the selection process for the adoption of new technologies in the supply chain (for example, [21,22]), there is a limited number of studies implementing such tools under the prism of CE in the food supply chain. Tarifa-Fernandez [23] conclude, each Small-Medium Enterprise (SME) has to make its selection upon its criteria that best serve the circularity of material flows. Following the suggestion of Tarifa-Fernandez [23], the selection process in this study is facilitated by employing the fuzzy TOPSIS principles, which signify the aspects of circularity that are satisfied when a company decides on a particular digital technology to be implemented. This study develops a methodological framework for the selection and evaluation of digital technologies in the context of a CSCM to respond to the following research question:

How do digital technologies make an impact on circularity in the context of food supply chain management?

The novelty of this paper stands on the fact that it integrates fuzzy TOPSIS into a methodological framework that can be applied in the industrial sector for appropriate selection of digital technologies. This framework can facilitate the process towards the achievement of sustainability and the creation of circular flows in the food supply chain. The motivation of this study is derived from the necessity to implement innovative technologies, so as to achieve sustainable development goals: Industry, Innovation and Infrastructure (9), and Responsible Consumption and Production (12) by 2050 [24].

The remainder of this article is as follows. Section 2 provides a methodological background focusing on the aspects of the circular economy and the impact of the chosen digital technologies on the CSCM. Section 3 presents the criteria for selecting digital technology as well as the detailed research methodology. Section 4 illustrates the research findings obtained via implementing the fuzzy TOPSIS. Sections 5 and 6 provide further discussion and implications and summaries key contributions, limitations, and future research directions.

2. Literature review

2.1. Circular economy

In the last few decades, CE has attracted substantial attention among researchers [25–29]. This concept has been established as an alternative operating and business model to the existing linear economic model unlike the circular economic model, there is a link between the linear material flow and several environmental issues [30]. Particularly, natural resource scarcity, environmental pollution, and increased volume of waste in any form are, among others, some of the consequences of the existing linear model of production and consumption [1]. On that basis, the CE concept constitutes an alternative and sustainable solution to address the challenges related to environmental problems [2,27,31].

Circular system as a restorative or regenerative system is designed to pave the way for sustainable development [32]. The fundamental operating principle of this "ecosystem" is based on the assumption that the system's boundaries align with those of the available resources are selflessly provided by the nature [32]. Lieder and Rashid [32] pointed out that it can be perceived as a closed-loop system where the materials and energy utilised within the system's boundaries are prevented from ending up in any form of waste because of the restorative processes followed in the ecosystem. Accordingly, employing the "cradle-to-cradle" approach, which is inherent within the context of CE, results in closed-loop circles [32]; this indicates that any waste produced is certainly not harmful to the environment, and, therefore, the environmental deterioration remains at a low level [33,34].

The "cradle-to-cradle" model constitutes the opposite of the "cradle-to-grave" model, which can be alternatively perceived as the linear economic model [35]. The first approach comprises a set of design principles according to which the depletion of materials at the end of the product's life cycle is prevented [36]. Thus, it is reasonable to conclude that the product design process plays a significant role in achieving circular material flows [35]. Additionally, Bocken [35,37] and De Angelis [8] pointed out that at an early stage, the details related to the materials of the product are taken into serious consideration since it is arguably resource-demanding to alter a product's features once it is made available to the market.

Transition towards the CE is, therefore, an emerging matter and implies a high degree of innovation, eco-friendly consciousness, and the implementation of appropriate business models from the point of view of a company [2,38]. The process of product design, as previously discussed, is an essential step towards CE. In terms of SCM, an enterprise should modify its infrastructure with respect to the principles that determine the circularity [2,39]. More specifically, the transition to CSCM indicates that the 3 R principles framework, namely, reduction, reuse and recycle, are being implemented as the most appropriate and relevant practices towards circularity [32,36,40].

2.2. Circular supply chain management

The imperative of operational sustainability and the establishment of a circular flow of materials within the realm of SCM represent paramount concerns, underpinned by an extensive body of scholarly literature [29,41–43]. According to Farooque [44], concepts of CE and SCM can be combined to lay the foundation for the conceptualisation and development of Circular Supply Chain Management (CSCM). Prior to analysing the integration of CE practices into the SCM domain, it is also essential to provide some fundamental principles of sustainable supply chain management. Under this context, a fair contribution is given to the performance objectives and goals related to society, the environment, and the economy [45]. However, in today's competitive business environment, several risks exist regarding the stability of the supply chains [8]. Price volatility, unpredictable weather conditions, and the increasingly insecure market are a stimulus for a tremendously unstable environment for doing business [8]. Therefore, reshaping the supply chain infrastructure is an essential step towards stable levels of operation and the smooth running of supply chains [46]. Recently, Vafadarnikjoo [47] developed a robust optimisation model to cope with such supply chain risks and mitigation strategies. The involvement of circular activities within the context of sustainable supply chain management is being treated as another practical solution towards mitigating the impact of the aforementioned risks [8,41].

The CSCM philosophy encompasses the regenerative and restorative characteristics entailed in the CE principles [43,44]. Indeed, the ultimate goal of CSCM is to utilise products to their maximum potential by prolonging their life span, while eliminating their waste [48,49]. Building on the existing literature on CSCM, one can identify that there are several business models to achieve circularity in the supply chain. Firstly, closed-loop supply chains comprise one of the most prominent circular supply chain models [7,41,50]. In this sense, immense value is obtained by companies that have adopted such business models. For instance, organisations undertake a series of measures to ensure zero waste is sent to landfills [8]. To achieve this, enterprises determine the extent to which the 3 R framework is implemented, considering the product at the end of its life cycle; the final goal is to distribute the reprocessed product back in the market without using additional resources [6]. Therefore, the product's life cycle broadens, while at the same time, its characteristics related to quality and functionality remain unaffected [51].

In the context of CSCM, it is essential for organisations to establish collaborative policies and activities within the supply chain network [8]. In fact, the circular flow of components implies that the materials are accessible by every actor within the circular supply chain [6,50]. Thus, collaboration is an indispensable feature of daily procedures and should determine the operational mode of CSCM [8].

Furthermore, there is a growing body in the literature that supports the idea that organisations should retain the ownership of a product [8, 52], *while offering it as a service to the final customer", [2]*; this, in turn, leads to increased product life and eliminates energy consumption [52]. According to Tukker [53], companies that offer their products as services realise fewer production rates and, therefore, energy consumption is barely perceptible.

2.3. Digital technologies in CSCM

The involvement of digital technologies in supply chain operations indicates the importance of leveraging the available technological means to transform the undergoing business practices into a more digitalised supply chain infrastructure. The transition to the forthcoming epoch of digitalisation has been already initiated. However, Manavalan and Jayakrishna [10] stated that enterprises across various industries still need to achieve satisfactory levels of integration of digital technologies within the SCM context. Accordingly, less evidence has been reported in the literature concerning the interrelation between the ideals of CE and the digital technologies, since these two concepts have yet to be examined synthetically [54,55].

The digital technologies constitute enablers according to which the principles of CE could be effectively implemented within the SCM boundaries [54,56–58]. In particular, the concept of Industry 4.0 has attracted a great deal of attention, with Germany being the first country that introduced this term in 2011 [59]. The central role of Industry 4.0 is to involve all the echelons that are part of industrial production [54]. For instance, the interconnection between stakeholders, such as manufacturers, suppliers, retailers and customers, is enabled through the contribution of breakthrough digital technologies [10]. Consequently, self-governed systems are being formed [60], seeking to optimise the decisions being taken regarding the design, development, customisation and distribution of a product, among other things [10].

The digitisation of the existing industrial systems is associated with the existence and constant evolution of both the Internet of Things and the Cyber-Physical System [12,13]. Cloud Manufacturing and Big Data Analytics are also considered essential technologies under Industry 4.0 [11,61,62]. Such disruptive digital technologies have the potential to serve CE goals by promoting resource efficiency, reducing waste, and increasing collaboration and innovation across the supply chain (for instance, [3,63–65]). To shed light on the core principles of these technologies, the potential advantages implied by their application are introduced [66] in the following sections.

2.3.1. Internet of things (IoT)

IoT is considered a modern concept of the manufacturing industry, according to which the physical and the digital world are interconnected by taking advantage of the internet's potential [10]. IoT constitutes a digital tool that facilitates the gathering, sharing and utilising the available data deriving from the manufacturing processes [11]. IoT provides real-time information sharing among the involved stakeholders by employing crucial technologies such as radio frequency identification (RFID) tags, sensors and smartphones [10,54]. It paves the way for a substantial increase in the efficiency of operations, optimisation of production, improved warehouse and logistics management and ameliorated product lifespan management [11,67].

2.3.2. Cyber-physical system (CPS)

A CPS underlies the interconnection between physical objects and several processes that occur within the manufacturing network [59]. In a CPS, computers, information technology systems, embedded systems, and humans share a vast amount of data to optimise the operations related to the manufacturing and production procedures [13], while providing trustworthy and effective communication channels. In that sense, a CPS has the potential to establish those principles by enabling the uninterrupted flow of information using several sensors and actuators [68]. Hence, exploiting a CPS provides automation, integration of all stakeholders, and self-driven and data-driven autonomous decision systems [68,69].

2.3.3. Cloud manufacturing (CM)

CM is a virtual manufacturing model according to which the resources related to the manufacturing processes and operations are monitored through the contribution of the Internet [54]. The CM model constitutes the virtual representation of the physical world [13,70] where several technologies are required for its efficient operation. More specifically, He and Xu [71] mentioned that *"among all the technologies, cloud computing and IoT deeply influence the development of cloud manufacturing"*. Cloud computing provides a cloud-based interpretation of the available manufacturing resources distributed on a large geographical scale [72]. Thereby cloud-based collaborative partnerships are structured within the value chain, e.g., suppliers, manufacturers and buyers, in terms of designing, manufacturing, and distributing a product [54].

2.3.4. Big data analytics (BDA)

Gathering, processing, and meaningful interpretation of data enable companies to generate large amounts of revenue. Organisations could employ BDA to decide how to exploit high volume and variety of information efficiently. For instance, optimal production line operation, accurate decision-making regarding the demand for a product, and better forecasting techniques are the main reasons a company should leverage BDA [72]. Overall, BDA provides a plethora of business information for enterprises to simplify complex data structures [11,73]. In line with this, Dubey [74] highlighted that companies should recruit employees that are suitable for implementing advanced BDA techniques.

2.4. The impact of digital technologies on CSCM

Each of the available technological means positively influences daily operations and manufacturing processes, making organisations capable of improving every aspect of the business functions. However, the scope of this research is to examine the extent to which digital technologies promote circularity in the context of SCM. The existing infrastructure of the supply chain needs to be conformed to the sustainability ideals as previously explained. As an appropriate solution, Yadav [75] argued the importance of aligning the digital technologies of Industry 4.0 with circularity towards sustainable development. Circular activities and Industry 4.0 are both innovative concepts that prepare the way for the sustainable supply chain of the future [14,76]. The benefits of each of the examined technologies will be analysed with respect to their contribution to enabling circularity.

2.4.1. Impact of IoT on CSCM

Manavalan and Jayakrishna [10] found that companies should seek digital opportunities to close the loop in their products. IoT is a robust solution towards addressing the challenges of achieving circularity [10,55,67]. In particular, IoT provides product traceability considering the condition of the materials that constitute the product itself [77]. Real-time information provided by IoT allows for more accurate implementation of the 3 R framework [54]. More specifically, any changes in the status of the product can be immediately detected, and therefore, supply chain stakeholders could decide whether the product can be reused or recycled [10]. Additionally, the Radio Frequency Identification (RFID) tags and sensors embedded in the machines provide relevant information in terms of the generated waste and resource efficiency [54]. Optimal production plans and efficient resource management techniques are employed by the relevant stakeholders [10]. Accordingly, several sensors satisfy the socio-environmental dimension of circularity adequately for the reason that the users of a product are informed about its materials' condition at any stage [54].

2.4.2. Impact of CPS on CSCM

Dependence on new materials is limited because a CPS provides the degree of traceability required for identifying how to cope effectively with the used products [13,78]. Real-time data access enables the evaluation of the performance of various operations within the production systems; thereby the available resources are not used non-sustainable. As a result, machines operate in the best possible way. Specifically, they are self-sufficient to make decisions regarding their performance and prevent the imminent overload that will induce a large amount of waste [54].

2.4.3. Impact of CM on CSCM

The usage of CM technologies gives rise to the creation of a collaborative supply chain network [13,79]. The representation of the physical world through the CM technology enables companies to establish service-oriented modes of operation [54]. According to Yang [52], companies that provide the servitisation of a product could leverage its life cycle to its maximum potential by deciding how many times a used product needs to be refurbished, recycled and remanufactured. Yu [80] pointed out that CM enables the interconnection between several supply chain echelons, namely, suppliers, manufacturers and customers. Moreover, Fisher [81] noted that the waste created in manufacturing processes could be treated as an input for producing another product. The authors mentioned that zero waste remains unexploited since the collaborative network of supply chain members, as mentioned above, monitors the waste and decides on its potential usage as a resource for another prospective product.

2.4.4. Impact of BDA on CSCM

Tseng [82], mentioned that BDA advocates the idea of fairly considering the levels of sustainability. Likewise, Mani [83] identified the impact of BDA on the environmental aspect of the CE since forecasting techniques become more meticulous and ensure minimised waste in any form. In terms of closing the loop in supply chains, Jabbour [84] highlighted that collaboration between supply chain partners is fundamental for forming a shared and environmentally-driven framework, where key stakeholders are taking mutual initiatives. Besides, BDA's raison d'etre is to provide an uninterrupted flow of information that stimulates the supply chain members to comply with the cooperatively established green policies [73].

2.5. Structure of a conceptual framework

The thorough exploration of the literature supports the conclusion that digital technologies provide several advantages in the context of SCM. Table 1 summarises the advantages associated with digital technologies in terms of indicating the supply chain and circular benefits, respectively. The purpose of this table is to provide the basis for the implementation of the data analysis procedure that this research has adopted (explained in Section **4.1)**.

Initially, the conceptual framework is structured based on the above findings. Then, in the next section, the methodology adopted in this study, namely, fuzzy TOPSIS, is thoroughly discussed. Additionally, it should be taken into account that the clusters of Decision Makers (DMs) are responsible for discriminating between several alternatives, considering the available digital technologies. Employing the fuzzy TOPSIS technique provides a ranking order of the options.

Consequently, the clusters of DMs could highlight the circular benefits, based on each digital technology, as emerged from the computation and the results of the fuzzy TOPSIS method. Once the calculations of the process are complete, the conceptual framework is enriched by identifying the specific supply chain attributes, which are interrelated with the supply chain and circular benefits correspondingly. The sequence of structuring the conceptual framework is illustrated in Fig. 1.

Table 1
The supply chain and circular economy benefits of each of the examined digital technologies.

Digital technologies	Supply chain benefits	Circular economy benefits
Internet of Things (IoT)	Continuous reporting on the status of materials that make up the product (**B1**) Ting[85], Manavalan[10]	Closed-loop supply chains Manavalan (9), Papanagnou [86]
	Improved warehouse and logistics management (**B2)** Zhong[11], Aravindaraj[87]	Implementation of the 3 R framework, namely reduction, reuse, recycle De Sousa Jabbour[54], Ding [88]
	Optimal production plans (**B3**) Manavalan[10], Angizeh[89]	Consumers are informed about a product's condition at any moment De Sousa Jabbour[54], Zhu [90]
Cyber-Physical Systems (CPS)	Evaluation of the performance of various operations within the production systems (**B4**) De Sousa Jabbour[54], Tucker [91]	Indication of how sustainably the resources are used during production De Sousa Jabbour[54], Plumpton[92] The production of waste is minimised within the manufacturing process de Sousa Jabbour[54], Fatimah[93]
Cloud Manufacturing (CM)	Self-driven and data-driven autonomous decision systems (**B5**) Wang[68], Haghnegahdar[94] Cloud-based interpretation of the available manufacturing resources (**B6**) Ghobakhloo[72], Liu[3]	Service-oriented modes of operation De Sousa Jabbour[54], Kamble Product's life span is extended Ren[95], Yang[52]
Big data analytics (BDA)	Advanced forecasting techniques to ensure efficient production line operation (**B7**) Mani[83], Rosati[96]	Minimised waste due to optimal production plans Mani[83], Benzidia[97]

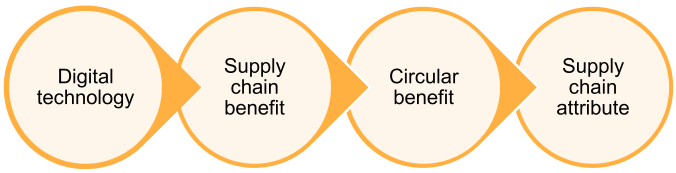

Fig. 1. An initial form of the conceptual framework.

3. Methodology

3.1. Case selection

The Food and Beverage industry constitutes one of the most significant branches of the Greek manufacturing sectors [98]. The transition towards sustainability stipulates that many beverage companies in Greece should redirect their activities, especially those related to SCM [98]. As discussed earlier, the circularity of operations in the context of SCM constitutes a feasible solution for sustainable development. According to Eurostat [99], Greece's circular material use rate was 6.3% in 2020, which was slightly lower than the European Union (EU) average of 11.7%. Nevertheless, Greece had a higher circular material use rate than other EU countries such as Bulgaria, Romania, and Cyprus. It is worth mentioning that the circular material use rate can be influenced by factors such as waste management practices, recycling infrastructure, and consumer behavior.

The Food and Beverage industry contributes significantly to the Greek economy. However, circular activities should be present in the Greek industry. In particular, the Greek economic model adopted by the Food and Beverage sector is linear. Therefore, it is crucial to consider how such a lucrative industry can be transformed to serve the CE purpose within the SCM context. In line with this, Manavalan and Jayakrishna [10] pointed out the importance of implementing digital technologies in the Food and Beverage industry to foster circularity in the supply chain. Accordingly, in Greece, a vast majority of enterprises from the Food and Beverage sectors are categorised as SMEs. Hence, the unit of analysis in this study is a beverage company of this category based in Greece.

The beverage company is called Company A and is located in Rhodes, one of the largest islands of south-eastern Greece. Company A is considered a SME that was founded in 1967, and it has had a strong business presence in the Food and Beverage sector since then. The company employs approximately 100 people, and its distribution network is designed to cover every corner of Greece. Further, considering the importance of the Food and Beverage industry in the Greek economy, as previously shown, the examined company constitutes an appropriate case study towards the investigation of the research question.

3.2. Criteria for selecting digital technologies

The transition to the digitalised era of SCM has already begun for organisations. In Section 2, a novel conceptual framework was formed to demonstrate how digital technologies influence circularity in the context of SCM.

According to Oztemel and Gursev [100], the transition to Industry 4.0 entails significant financial benefits for companies. Indeed, the technological trends result in optimal production systems [10] alongside improved warehouse management [11] increasing benefits for enterprises. Therefore, the first criterion that organisations should take into consideration when evaluating digital technologies is that of profit.

Considering the choice of criteria from a different perspective, Bocken [35] pointed out that innovation is an inherent characteristic of circular business models. In line with this, the digital transformation of the supply chain also correlates with a high degree of innovation [101]. Additionally, digitalisation can be perceived as a promoter of circularity [54,102]. Hence, innovation is identified as the second criterion to be taken into account by companies that have the intention to adopt digital technologies.

A growing body of literature supports the view that one of the main elements of CE is sustainability [36,75]. More specifically, the advanced technological means and trends underpin the transition to sustainable development [75]. To the same extent, Liao [103] highlighted that companies with aspirations to transit towards Industry 4.0 could efficiently encounter sustainability-related challenges. Therefore, the sustainability criterion is also added to the selection process of digital technologies.

Rajput and Singh [104] pointed out that within the digitally transformed factory, a series of optimal decisions occurs from the perspective of the "smart" machines. According to the authors, this lies in the fact that the interaction between smart technologies is such that it enables optimal resource efficiency. Additionally, Bag [61] mentioned that the integrated digital technologies of Industry 4.0 support optimisation. For this reason, optimisation is selected as the fourth criterion to consider when a group of DMs is under the decision-making process on selecting several technologies. Considering the guidelines provided by the study of Chhimwal [105], the following criteria (see Table 2) have been selected and linked with similar research articles.

3.3. Data collection

The scope of this study is to evaluate the benefits derived from implementing digital technologies in the context of CSCM. For this purpose, groups of decision makers (DMs) involved in the supply chain management, supply chain innovation and quality management and control are required to signify their preferences on this matter. To collect preferences of DMs, a self-completion questionnaire (please refer to Appendix A) is used as the data gathering tool containing questions about four criteria: profit, innovation, sustainability, and optimisation (see discussion in Section 3.2). The sampling process involved distributing self-completion questionnaires electronically to the three clusters of DMs currently employed in the Company A (cluster description is provided in Table 3). Respondents were invited to answer several rating questions about the benefits of implementing digital technologies.

The selection of experts/decision-makers for this study was based on their roles and responsibilities within Company A. DM1 represents the tactical management level within the supply chain. Qualifications likely include a background in logistics, inventory management, and operational supply chain processes. They are experienced in day-to-day supply chain operations. DM2 represents the strategic management level within the supply chain. Qualifications likely include advanced education or training in supply chain strategy, market analysis, and long-term planning. They are responsible for making high-level strategic decisions. DM3 is associated with the Quality Assurance Group, indicating expertise in quality control processes. Qualifications likely include a

Table 2
The supply chain and circular economy benefits of each of the examined digital technologies.

Criteria	Selection	References
(C1) Profit	The adoption of circular economy tools should be justified from the economic viability of an enterprise.	Ariztia[106], Khan[107]
(C2) Innovation	Necessity for customers' involvement towards the creation of innovative sustainable circular products using digitalization.	Bressanelli [108], Kurniawan [109]
(C3) Sustainability	Incorporating sustainability principles and practices in the circular business model.	Ozkan-ozen [110], Schöggl[111]
(C4) Optimisation	Efficient use of resources serving the 5 R's principle (Refuse, Reduce, Reuse, Repurpose, Recycle)	Wang[112], Khan[107]

Table 3
The list of research participants-clusters.

Clusters of Decision-Makers	Cluster Description
DM1	Supply chain – Tactical Management
DM2	Supply chain – Strategic Management
DM3	Quality Assurance Group

background in quality management, adherence to industry standards, and a focus on product and process quality.

Overall, 65 questionnaires were collected out of 100 employees, preserving the stratification of roles and the diversity of perspectives in this entity. The sample size suggests a relatively good response rate, which can contribute to the validity of the results. To further analyse this dataset, Principal Component Analysis (PCA) was implemented to highlight the main cluster of the decision makers in Company A. It should be underlined that Kaiser-Mayer-Olkins (KMO) (0.715), and Barlett's sphericity test (p-value < 0.01) requirements have been met, indicating that the analysis techniques employed were statistically appropriate. The three DM clusters showcase different attributes that are briefly summarised in Table 3.

For this research project, quantitative data is required to employ the fuzzy TOPSIS method, which will be discussed extensively in the following section. However, it is essential to accentuate that previous studies, whose primary research method is fuzzy TOPSIS, also employed a small sample size due to the illustrative nature of this method.

3.4. Fuzzy TOPSIS

The selection of the most appropriate digital technologies, in the context of CSCM, embodies complicated judgements on the DMs' side. Regarding this matter, Chen [16] suggested an extension of the classical TOPSIS method, namely the fuzzy TOPSIS method. This method constitutes an MCDM method. Before elaborating on the concept of fuzzy TOPSIS, it is particularly significant to emphasise some applications of this method in reference to the SCM literature. Kannan [18], for instance, utilised fuzzy TOPSIS to identify and select green suppliers based on their "green" activity in the context of SCM. Mahpour [113] used the fuzzy TOPSIS method to establish priorities among the barriers towards circularity. Agrawal [27] made use of such a technique to analyse roadblocks to the adoption of CE in the Indian automobile industry. [114] used fuzzy TOPSIS and fuzzy Best-Worst method to identify the location of sustainable collection centres for e-waste. Toker and Görener [115] considered the implementation of the spherical fuzzy TOPSIS method to evaluate a set of circular economy business models for SMEs. Table 4 briefly summarises some of the most recent studies implementing the fuzzy TOPSIS method, as a decision analysis approach under the prism of circular economy.

In the fuzzy TOPSIS technique, linguistic variables are being used instead of numerical variables since numerical expressions are viewed as inadequate to reveal the preferences of DMs under a fuzzy environment [17]. The number of criteria is determined, and the importance weight is assigned to each criterion by linguistic means [16]. In this research project, the fuzzy TOPSIS proposed by Chen [16] has been adopted. It is important to mention that our study assumes that the criteria involved are independent of each other, in that the evaluation of one criterion does not impact the evaluation of the other criteria; this highlights the reason of implementing the conventional fuzzy TOPSIS method instead of the weighted one. Tables 5 and 6 illustrate the linguistic variables labelled as positive triangular fuzzy numbers.

According to Chen [16], a group comprised of K DMs is being formed. Subsequently, the DMs use the linguistic variables, as presented above, not only to assign importance weights to each criterion respectively but also to rate the proposed alternatives with a view to the suggested criteria [17]. Accordingly, the importance weights and the ratings of the alternatives can be calculated using the following equations [16]:

Table 4
Assessing the implementation of Fuzzy TOPSIS on a circular economy approach.

Authors & Year	Application	Methodology	Selection Criteria	Findings
Kannan (2014)	Logistics- (Green supplier selection)	Fuzzy TOPSIS	17 criteria involving the infrastructure of the selected supplier companies and their relationships with clients	Identification of the most significant criteria: (1) Managers dedication to green practices, (2) Green product design (3) Fulfilling green law requirements (4) Hazardous material use reduction
Husain et al. (2021)	Operations Management (Circular economy)	Fuzzy TOPSIS	9 Criteria: (1) Partnership (2) Activities (3) Resources (4) Value Proposition (5) Customer Relationships (6) Distribution Channels (7) Client Segments (8) Cost structure (9) Revenue Flows	Identification of the most appropriate product and process design for a shift towards a circular economic system
Agrawal et al. (2020)	Automobile sector	Fuzzy TOPSIS	20 potential roadblocks as criteria	Identification of the most crucial roadblock acting as a barrier to circular economy adaptation
Sagnak et al. (2021)	Logistics- (e-waste collection)	Fuzzy Best-Worst & Fuzzy TOPSIS	3 main categories with 23 sub-criteria in total for 7 regions: (1) Economic (2) Social (3) Environmental	Transportation cost as the most important criterion and Çiğli as the best alternative for sustainable collection centre
Toker & Görener (2023)	Operations Management & SMEs (Circular economy)	Spherical Fuzzy TOPSIS	4 main categories with 12 sub-criteria in total: Restore and ReduceRethink and ReconfigureSkills and CapabilitiesFiscal Durability	SMEs managers should focus on developing internal processes (application of appropriate business models) towards smooth transition to circular economy.
Hajiaghaei-Keshteli et al. (2023)	Logistics- (Green supplier selection)	Pythagorean Fuzzy TOPSIS	27 criteria involving focusing on 4 different categories: (1) Operational and Logistics (2) Economic (3) Social & Marketing (4) Environmental	Identification of the most suitable green supplier for the supply of cardboard boxes for the food industry.

Table 5
Linguistic variables assigned to express the weight of each criterion.

Importance	Weight
Very Low (VL)	(0, 0, 0.1)
Low (L)	(0, 0.1, 0.3)
Medium Low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium High (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1.0)
Very High (VH)	(0.9, 1.0, 1.0)

Source: Adapted from Chen [16]

Table 6
Linguistic variables to express the ratings of each alternative.

Importance	Weight
Very Poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium Poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium Good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very Good (VG)	(9, 10, 10)

Source: Adapted from Chen [16]

$$\widetilde{X}_{ij}\& = \frac{1}{K}\left[\widetilde{X}_{ij}^{\ 1}(+)\widetilde{X}_{ij}^{\ 2}(+)\ldots(+)\widetilde{X}_{ij}^{\ K}\right] \tag{1}$$

$$\widetilde{W}_{j}\& = \frac{1}{K}\left[\widetilde{W}_{j}^{\ 1}(+)\widetilde{W}_{j}^{\ 2}(+)\ldots(+)\widetilde{W}_{j}^{\ K}\right] \tag{2}$$

Where the Kth decision-maker indicates their $\widetilde{X}_{ij}^{\ K}$ rating of each alternative, followed by their assigned $\widetilde{W}_{j}^{\ K}$ importance weight of each defined criterion.

Following the fuzzy TOPSIS method proposed by Chen [16], it is essential to point out that a fuzzy MCDM problem could be displayed in an array form. As such, the fuzzy decision matrix is presented below to illustrate the examined MCDM problem:

$$\widetilde{D} = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} & \ldots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \ldots & \widetilde{x}_{2n} \\ \vdots & \vdots & \ldots & \vdots \\ \widetilde{x}_{m1} & \widetilde{x}_{m2} & \ldots & \widetilde{x}_{mn} \end{bmatrix} \tag{3}$$

$$\widetilde{W} = \left[\widetilde{W}_1, \quad \widetilde{W}_2, \quad \ldots, \quad \widetilde{W}_n\right] \tag{4}$$

Where each element of array $\widetilde{D}$, $\forall$ij, specifically $\widetilde{X}_{ij}$ constitutes a linguistic expression. Also, each component of array $\widetilde{W}$, $\forall$ij, namely $\widetilde{W}_j$, $j = 1, 2, \ldots, n$, is considered a linguistic variable. The linguistic variables of these arrays can be denoted as triangular fuzzy numbers of the following format, $\widetilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\widetilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$, respectively [16].

The next step of the fuzzy TOPSIS method relates to the formation of the normalised fuzzy matrix illustrated by $\widetilde{R}$. The importance of normalisation is such that it ensures that the triangular fuzzy numbers belong to the closed interval [0,1] [17]. In line with this, the matrix $\widetilde{R}$ is composed as follows:

$$\widetilde{R} = \left[\widetilde{r}_{ij}\right]_{m\times n} \tag{5}$$

$$\widetilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^{\ *}}, \frac{b_{ij}}{c_j^{\ *}}, \frac{c_{ij}}{c_j^{\ *}}\right), j \in B \tag{6}$$

$$\widetilde{r}_{ij} = \left(\frac{a_j}{c_{ij}}, \frac{a_j}{b_{ij}}, \frac{a_j}{a_{ij}}\right), j \in C \tag{7}$$

$$c_j^{*} = \max c_{ij} \text{ if } j \in B \tag{8}$$

$$a_j^{\ -} = \min a_{ij} \text{if} j \in C \tag{9}$$

where B composes a set of benefit criteria, while C constitutes a set of cost criteria correspondingly [16].

In the next stage, the weighted normalised fuzzy matrix is being constructed in the following manner.

$$\widetilde{V} = \left[\widetilde{u}_{ij}\right]_{mxn}, i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n \tag{10}$$

where $\widetilde{u}_{ij} = \widetilde{r}_{ij}(\bullet)\widetilde{w}_j$.

Once the weighted normalised fuzzy matrix $\widetilde{V}$ is determined, then the fuzzy positive-ideal solution (FPIS, A^*) and fuzzy negative-ideal solution (FNIS, A^-) [16] are determined by the following formulas:

$$\& A^* = \left(\widetilde{u}_1^{\ *}, \widetilde{u}_2^{\ *}, \ldots, \widetilde{u}_n^{\ *}\right) \\ \& \tag{11}$$

$$A^- = \left(\widetilde{u}_1^{\ -}, \widetilde{u}_2^{\ -}, \ldots, \widetilde{u}_n^{\ -}\right) \tag{12}$$

where $\widetilde{u}_j^{\ *} = (1,1,1)$ and $\widetilde{u}_j^{\ -} = (0,0,0)$ $\forall j = 1, 2, \ldots, n$.

Then, the distance of each of the proposed alternatives from FPIS and FNIS respectively, should be defined using the following procedure [16]:

$$d_i^{\ *} = \sum_{j=1}^{n} d\left(\widetilde{u}_{ij}, \widetilde{u}_j^{\ *}\right) \tag{13}$$

$$d_i^{\ -} = \sum_{j=1}^{n} d\left(\widetilde{u}_{ij}, \widetilde{u}_j^{\ -}\right) \tag{14}$$

where $j = 1, 2, \ldots, m$, $d(\widetilde{u}_{ij}, \widetilde{u}_j^{\ *})$ and $d(\widetilde{u}_{ij}, \widetilde{u}_j^{\ -})$ indicate the distance between two triangular fuzzy numbers which can be calculated by the following equation [16]:

$$d(\widetilde{m}, \widetilde{n}) = \sqrt{\frac{1}{3}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2\right]} \tag{15}$$

Finally, the fuzzy TOPSIS is completed once the closeness coefficient is calculated considering the order of preference for all of the examined alternatives $A_i(i = 1,2,\ldots,m)$. The following formula is used to calculate the closeness coefficient of each of the proposed options:

$$CC_i = \frac{d_i^-}{d_i^{\ -} + d_i^-}, i = 1, 2, \ldots, m. \tag{16}$$

The values of the closeness coefficient which are close to 1 denote that an alternative A_i is closer to the FPIS and at a greater distance from the FNIS, which is desirable in fuzzy TOPSIS method. Having computed the closeness coefficient of each alternative, then the order of rank is known, indicating what is considered the optimum choice among all the proposed options [16].

4. Findings

4.1. Results of fuzzy TOPSIS

Company A is considered an SME and has a strong business presence in Greece's Food and Beverage sector. The transition towards circularity implies a series of changes to transform the supply chain infrastructure. Consequently, a committee of three clusters of DMs (DM1, DM2, DM3) has been formed to evaluate the potential benefits from seven identified benefits (B1, B2, B3, B4, B5, B6, B7) of the examined digital technologies. The rationale for considering which criteria are essential in the decision-making process has been explained in greater detail in Section 3.2. To this end, four benefit criteria are taken into account:

(1) Profit (C1).
(2) Innovation (C2).

(3) Sustainability (C3).
(4) Optimisation (C4).

The hierarchical structure of the examined decision problem, namely the selection of the most appropriate digital technology, is showcased in Fig. 2.

As presented in Section 2.5, the potential benefits are illustrated as follows. Additionally, the benefits associated with each digital technology are shown in Table 7.

B1: Continuous reporting on the status of materials that make up the product.

B2: Improved warehouse and logistics management.

B3: Optimal production plans.

B4: Evaluation of the performance of various operations within the production systems.

B5: Self-driven and data-driven autonomous decision systems.

B6: Cloud-based interpretation of the available manufacturing resources.

B7: Advanced forecasting techniques to ensure efficient production line operation.

The fuzzy TOPSIS technique, as illustrated in Section 3.4, has been employed. The computational process of the method is completed in nine steps as follows.

Step 1: The cluster DMs (DM1, DM2, DM3) assign the linguistic variables (see Table 5) to the four criteria (C1, C2, C3, C4) to express the importance weight of each criterion. In Table 8, the importance weights of the criteria are shown.

Step 2: The cluster DMs (DM1, DM2, DM3) use the linguistic variables (see Table 6) in order to evaluate the ratings of the potential benefits of the examined digital technologies in relation to C1, C2, C3 and C4, respectively. The results are presented in Table 9.

Step 3: The linguistic expressions of Tables 8 and 9 can also be denoted as triangular fuzzy numbers. Once the triangular fuzzy numbers are computed, the fuzzy decision matrix is formed, followed by the fuzzy weights of C1, C2, C3 and C4, respectively. The results are demonstrated in Table 10.

Step 4: The fuzzy normalised decision matrix is illustrated in Table 11.

Step 5: The fuzzy weighted normalised decision matrix is constructed in Table 12.

Step 6: The fuzzy positive-ideal solution (FPIS, A^*) and the fuzzy negative-ideal solution (FNIS, A^-) are defined as:

$$A^* = [(1,1,1),(1,1,1),(1,1,1),(1,1,1)]$$

Table 7
Benefits associated with each digital technology.

Digital technology	Supply chain benefits
IoT	B1, B2, B3
CPS	B4
CM	B5, B6
BDA	B7

Table 8
Importance weights of C1, C2, C3, C4.

Criteria	Clusters of Decision-Makers		
	DM1	DM2	DM3
C1	MH	VH	H
C2	MH	MH	H
C3	H	M	H
C4	H	MH	H

$$A^- = [(0,0,0),(0,0,0),(0,0,0),(0,0,0)]$$

Step 7: The distance of each alternative (benefit) from FPIS and FNIS, respectively, is calculated in Table 13.

Step 8: The closeness coefficient is computed for each alternative in Table 14.

Step 9: In reference to the closeness coefficient of each option, the order of rank is shown in Table 15.

The ranking order of the examined benefits of digital technologies is the following:

B4>B1>B5>B3>B7>B6>B2

or.

CPS>IoT>CM>BDA

The results of the fuzzy TOPSIS indicate that B4 (evaluation of the performance of various operations within the production systems), is considered the most significant benefit of digital technologies among the examined alternatives. Therefore, drawing on the preferences of the three clusters of DMs, it is suggested that Company A should implement a CPS as its core digital technology since this is strongly associated with the aforementioned benefit. Besides, the employment of a CPS implies that the resources used during production are used in a sustainable

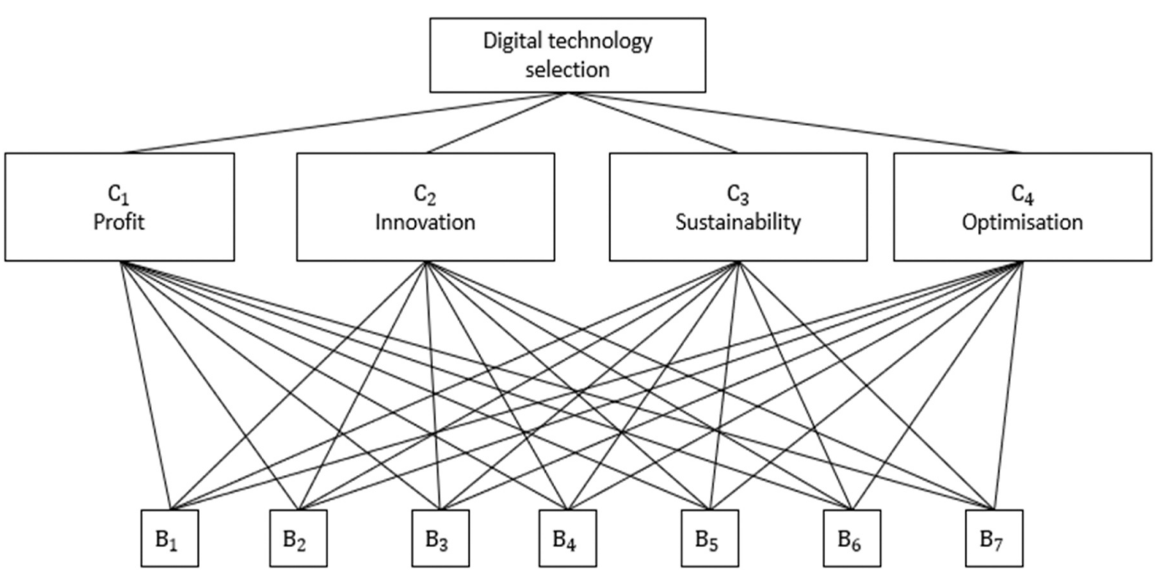

Fig. 2. Hierarchical structure.

Table 9
Ratings of the benefits with respect to each criterion.

Criteria	Benefits	Clusters of Decision-Makers		
		DM1	DM2	DM3
C1	B1	G	MG	G
	B2	MG	MG	G
	B3	MG	F	G
	B4	MG	G	G
	B5	G	MG	G
	B6	G	F	G
	B7	MG	F	G
C2	B1	G	MG	G
	B2	G	F	G
	B3	G	G	G
	B4	G	VG	G
	B5	MG	MG	G
	B6	MG	F	G
	B7	G	MG	G
C3	B1	G	MG	G
	B2	G	MP	VG
	B3	G	F	G
	B4	G	MG	G
	B5	G	F	G
	B6	G	MG	G
	B7	G	F	VG
C4	B1	G	MG	G
	B2	G	F	G
	B3	G	MG	G
	B4	G	MG	VG
	B5	G	G	G
	B6	G	F	G
	B7	G	MG	VG

Table 10
Fuzzy decision matrix and fuzzy weights of seven alternatives.

Benefits	Criteria			
	C1	C2	C3	C4
B1	(6.3, 8.3, 9.7)	(6.3, 8.3, 9.7)	(6.3, 8.3, 9.7)	(6.3, 8.3, 9.7)
B2	(5.7, 7.7, 9.3)	(5.7, 7.7, 9)	(5.7, 7.3, 8.3)	(5.7, 7.7, 9)
B3	(5, 7, 8.7)	(7, 9, 10)	(5.7, 7.7, 9)	(6.3, 8.3, 9.7)
B4	(6.3, 8.3, 9.7)	(7.7, 9.3, 10)	(6.3, 8.3, 9.7)	(7, 8.7, 9.7)
B5	(6.3, 8.3, 9.7)	(5.7, 7.7, 9.3)	(5.7, 7.7, 9)	(7, 9, 10)
B6	(5.7, 7.7, 9)	(5, 7, 8.7)	(6.3, 8.3, 9.7)	(5.7, 7.7, 9)
B7	(5, 7, 8.7)	(6.3, 8.3, 9.7)	(6.3, 8, 9)	(7, 8.7, 9.7)
Weights	(0.7, 0.87, 0.97)	(0.57, 0.77, 0.93)	(0.57, 0.77, 0.9)	(0.63, 0.83, 0.97)

Table 11
Fuzzy normalised decision matrix.

	C1	C2	C3	C4
B1	(0.65, 0.85, 1)	(0.63, 0.83, 0.97)	(0.65, 0.85, 1)	(0.63, 0.83, 0.97)
B2	(0.59, 0.79, 0.96)	(0.57, 0.77, 0.9)	(0.59, 0.75, 0.85)	(0.57, 0.77, 0.9)
B3	(0.51, 0.72, 0.9)	(0.7, 0.9, 1)	(0.59, 0.79, 0.93)	(0.63, 0.83, 0.97)
B4	(0.65, 0.85, 1)	(0.77, 0.93, 1)	(0.65, 0.85, 1)	(0.7, 0.87, 0.97)
B5	(0.65, 0.85, 1)	(0.57, 0.77, 0.93)	(0.59, 0.79, 0.93)	(0.7, 0.9, 1)
B6	(0.59, 0.79, 0.93)	(0.5, 0.7, 0.87)	(0.65, 0.85, 1)	(0.57, 0.77, 0.9)
B7	(0.51, 0.72, 0.9)	(0.63, 0.83, 0.97)	(0.65, 0.82, 0.93)	(0.7, 0.87, 0.97)

manner, ensuring that the production of waste is minimised within the manufacturing process [54].

As already discussed, digital technologies offer a plethora of benefits to companies that consider them to enable circularity in the context of SCM. In the following section, the conceptual framework, as proposed in Section 2.5, is enriched by providing additional circular benefits of digital technologies with emphasis on the attributes imparted to the supply chain. Thus, the extent to which each digital technology helps organisations operate under CE ideals is viewed.

Table 12
Fuzzy weighted normalised decision matrix.

	C1	C2	C3	C4
B1	(0.45, 0.74, 0.97)	(0.36, 0.64, 0.9)	(0.37, 0.65, 0.9)	(0.4, 0.69, 0.94)
B2	(0.41, 0.69, 0.93)	(0.32, 0.59, 0.84)	(0.34, 0.58, 0.76)	(0.36, 0.64, 0.87)
B3	(0.36, 0.63, 0.87)	(0.4, 0.69, 0.93)	(0.34, 0.61, 0.84)	(0.4, 0.69, 0.94)
B4	(0.45, 0.74, 0.97)	(0.44, 0.72, 0.93)	(0.37, 0.65, 0.9)	(0.44, 0.72, 0.94)
B5	(0.45, 0.74, 0.97)	(0.32, 0.59, 0.86)	(0.34, 0.61, 0.84)	(0.44, 0.75, 0.97)
B6	(0.41, 0.69, 0.9)	(0.28, 0.54, 0.81)	(0.37, 0.65, 0.9)	(0.36, 0.64, 0.87)
B7	(0.36, 0.63, 0.87)	(0.36, 0.64, 0.9)	(0.37, 0.63, 0.84)	(0.44, 0.72, 0.94)

Table 13
Distance of each benefit from FPIS and FNIS.

	Distance from FPIS	Distance from FNIS
B1	1.59	2.81
B2	1.76	2.58
B3	1.66	2.7
B4	1.49	2.88
B5	1.61	2.76
B6	1.74	2.62
B7	1.65	2.69

Table 14
Closeness coefficient.

	Closeness coefficient CC_i
B1	0.64
B2	0.59
B3	0.6198
B4	0.66
B5	0.63
B6	0.6
B7	0.6192

Table 15
Ranking of the alternatives.

	Order of rank
B1	2
B2	7
B3	4
B4	1
B5	3
B6	6
B7	5

5. Discussion

5.1. Additional circular benefits of proposed digital technologies

In Section 2, the basis of the conceptual framework regarding the adoption of digital technologies that serve the CE was established. Following the results acquired through the fuzzy-TOPSIS model (see Section 4), extensions of this framework can be found in this section embodying circular economy benefits and supply chain attributes.

5.1.1. Circular benefits of CPS

The computation of the fuzzy TOPSIS (see Section 4) approach gives prominence to the implementation of a CPS by the examined company. As discussed in Section 2, the benefits of a CPS, in terms of circularity, allow companies to understand whether the resources, which are essential for the production process, are utilised in a sustainable way [54]. Accordingly, leveraging a CPS assumes that the generated waste is kept to the minimum percentage possible [54]. In addition, Manavalan and Jayakrishna [10] found that CPS allows companies to identify the sustainability levels of operating machines and prolong their life cycle. In line with this, Rosa [116] also argued that such a technology can promote sustainable maintenance activities. Therefore, through its implementation, the emphasis is placed on a product's life span management, ranging from the creation of the product to the maintenance of the machine that is responsible for producing it [117].

Furthermore, one prominent feature of a CPS is the real-time information it provides to the members of the supply chain network [13]. According to Ellen MacArthur Foundation [118], real-time monitoring of resources, operating machines, and generated waste lays the groundwork for elevated levels of traceability and transparency. In essence, within the collaborative supply chain network, waste could be redistributed to the manufacturers as raw materials rather than ending up in a landfill [118]. In Fig. 3, the proposed conceptual framework of Section 2, is enriched regarding the circular benefits and the supply chain attributes of the CPS digital technology.

5.1.2. Circular benefits of IoT

In line with the analysis of fuzzy TOPSIS (see Section 4), IoT-enabled digital technologies are evaluated as the second most suitable technology for implementation by the clusters of DMs of Company A. In particular, IoT-enabled technologies, such as sensors, RFID and tags, could foster the transition towards circular supply chain infrastructure field [118]. As discussed in Section **2**, the advanced technological means entailed in IoT contribute to the acceleration of closing the loop within the supply chain network [10]. A closed-loop supply chain constitutes an essential circular business model, in which a product is refurbished, reused or recycled [6]. As a result, this flow of materials within the production processes enables reverse logistics approaches, which, in turn, trigger increased sustainability levels for organisations [41].

Moreover, IoT-enabled technologies facilitate the transition to a more cooperative stakeholder network in terms of the supply chain [119]. The authors highlighted that the condition and quality of a product could be traced through the interconnectivity that defines IoT. Consequently, organisations *"contain valuable information on how the product was utilized by the customer"* [119]. Thus, organisations recognise potential modifications that should be implemented to extend the product's life cycle. In Fig. 4, the conceptual framework related to IoT-enabled technologies is improved.

5.1.3. Circular benefits of CM

Drawing on the fuzzy TOPSIS, CM is ranked as the third choice among the examined digital technologies. As emerged from Section **2**, CM is strongly associated with service-oriented circular business models [52,54]. In such models, organisations could benefit financially since a low volume of resources is required for making adjustments in a used product that is being offered to customers as a service [35]. Thus, the whole supply chain infrastructure becomes more flexible, and cost-effective.

From a different perspective, Fisher [81] argued that CM technology creates opportunities to enterprises in terms of viewing waste *"as a valuable resource to be reused, recovered and regenerated"*. Therefore, it reasonably follows that satisfactory levels of sustainability are attained. Fig. 5 depicts the improved conceptual framework in relation to CM.

5.1.4. Circular benefits of BDA

The calculations of the fuzzy TOPSIS method indicate that BDA constitutes the least preferred digital technology among the discussed technologies. *BDA is also perceived to be a facilitator for decision making.* In terms of CSCM, the authors mentioned that BDA provides fruitful insights to organisations on how to make sense of the large volume of data deriving from the production procedures. More specifically, firms that leverage BDA could achieve efficient resource management [83], and therefore, the utilisation of resources is a data-driven process in line with the sustainable way of production. At this point, one can observe that the supply chain infrastructure turns out to be data-driven regarding the decision-making process. In Fig. 6, the conceptual framework of BDA is also enriched concerning the findings derived from Section 2.

5.2. Implications

As emerged from Neri [120], SMEs showcase different needs that should be fulfilled by the smooth adaptation of digital technologies. That is mainly the reason why the proposed approach has been developed to facilitate this process. The selection process can be influenced by various factors such as internationalisation and operational behavioural factors [1,121]. In other words, an enterprise's extroversion level and internal structure play a huge role in determining the digital pathway in line with its preserved values. Moreover, a restrictive factor of digital technology adoption is the initial investment in the financial resources [122], along with the appropriate timeframe for the embodiment of these conceptual changes within the enterprise infrastructure.

From a managerial perspective, more practical evidence is required in shaping a more robust conceptual framework that would indicate not only the circular benefits of digital technologies but also the dimension of circularity that is satisfied, namely, people, planet, and profit. On that basis, organisations could leverage the fuzzy TOPSIS method as a useful managerial tool to further explore how they could achieve higher levels of circular flows and by what means. In other words, the implementation of Fuzzy TOPSIS can provide rational decisions regarding the selection of the appropriate digital technology. By this means, the overall performance of an SME can be increased, given the fact that the final decision was acquired by considering the scale and ordinal data related to

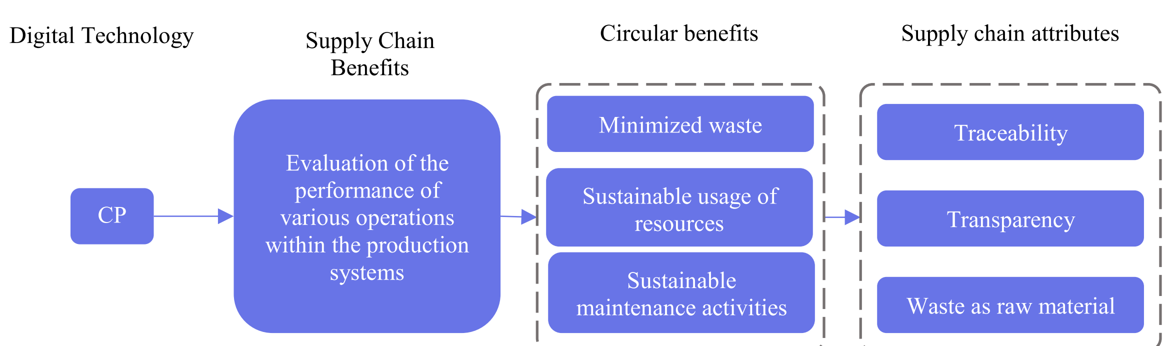

Fig. 3. Enriched conceptual framework of CPS.

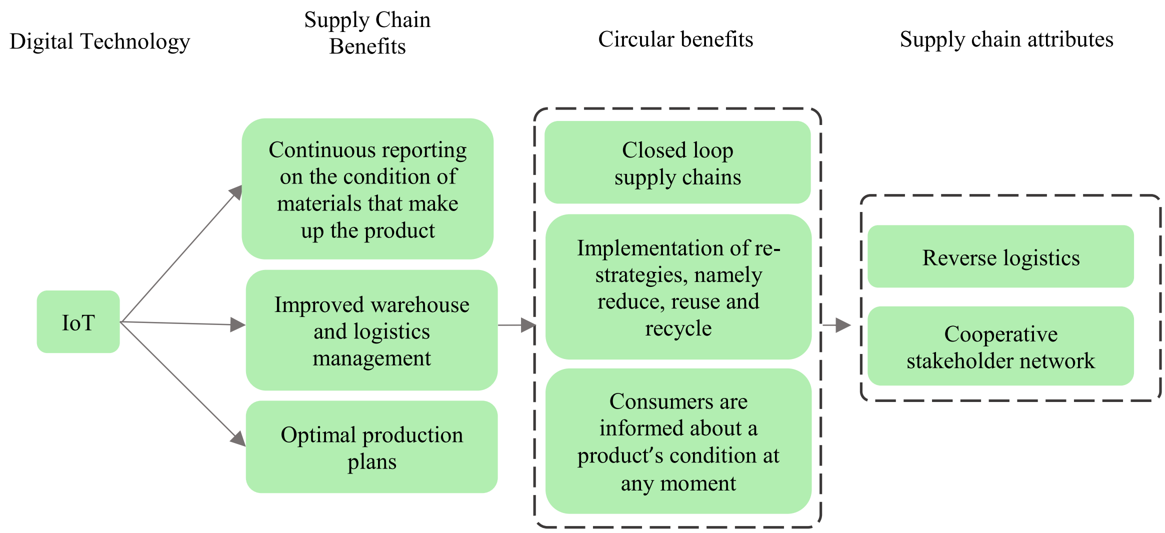

Fig. 4. Enriched conceptual framework of IoT.

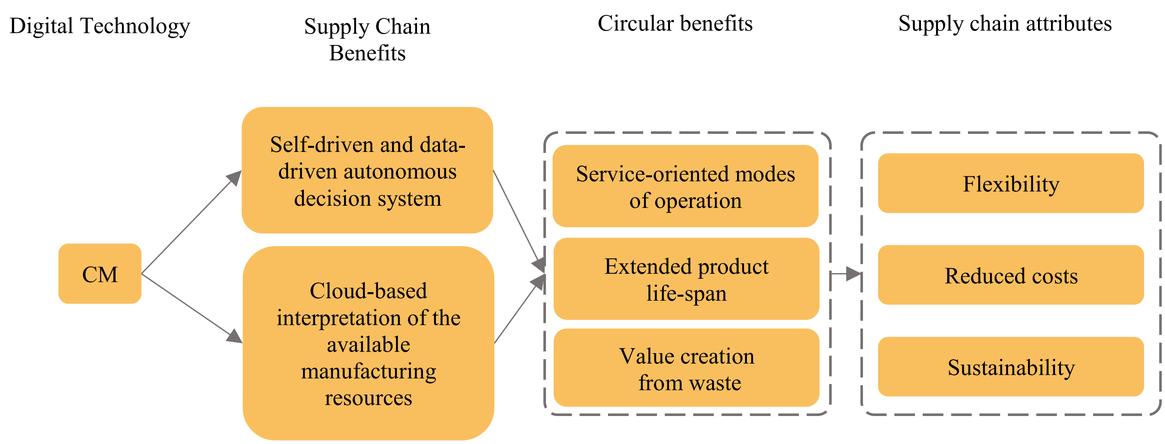

Fig. 5. Enriched conceptual framework of CM.

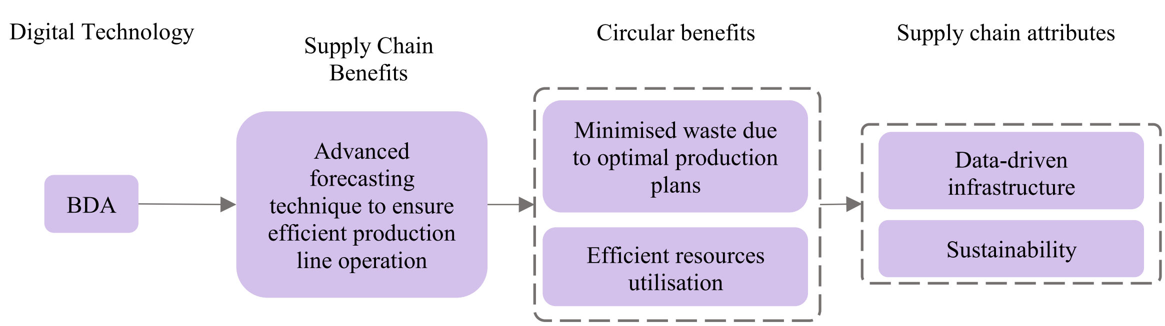

Fig. 6. Enriched conceptual framework of BDA.

the employee's needs of each enterprise.

This study offers a wide plethora of implications from a theoretical perspective. Firstly, the four criteria and the seven supply-chain benefits integrated into this study will provide a deeper understanding of the problem situation. This can be beneficial to scholars and research and development managers towards the assessment of all potential options for digital technology implementation in a circular economy context. Secondly, in this study, all different roles of employees have been considered depicting a concrete view of their attitudes. Finally, this study provides initiatives for elucidating the interconnections among the selected benefits and criteria which may be a guideline for future researchers active in the operational research or supply chain analytics field.

6. Conclusion

This research study explored how the available digital technologies (CPS, IoT, CP, BDA) impact circularity in the context of SCM. The motivation for further investigation of this issue was the identified research gap in the literature that considers the concepts of CE, digital technologies, and SCM. Due to the fact that digital technologies are essential for accurate feedback acquisition and that they are expected to be implemented from human beings, it is deemed appropriate to enable digital technologies benefits with employees preferences. Considering this aspect, PCA has been applied to assess employees' attitudes towards this digitalisation process.

Regarding digital technologies, we lay the foundation for developing a novel conceptual framework (see Fig. 1) highlighting the supply chain attributes that are derived from the supply-chain and circular benefits. A single case study was examined to understand the nature of this issue. The data collection was performed by distributing questionnaires to the company staff. The illustrative scope of this research enabled the utilisation of the fuzzy TOPSIS methodology as the appropriate method for data analysis. The usefulness of the method lies in the fact that when the ranking order of the alternative options (digital technologies) is obtained, then the decision-making committee of an organisation can automatically determine the precise circular benefits associated with each digital technology. Easier identification of the desired outcome can facilitate the process of creating circular flows on the conventional linear economic model.

Consequently, an enterprise that aspires to transform the supply chain infrastructure by digitalised means could rely on the fuzzy TOPSIS technique. This will highlight not only the most appropriate technology for implementation but also the particular characteristics of circularity imparted upon the implementation of each technology. This method can be implemented by researchers and practitioners in other similar decision-making processes that impact the selection of digital technologies for an entity. Appropriate selection of digital technologies can increase the potential of transition to a circular economy concept, which is a high-priority issue on a global scale. Lastly, the conceptual framework, as proposed in Section 2, is enriched in discerning the supply chain attributes when the circular benefits are known, following the selected digital technology.

6.1. Limitations

This research study carries some limitations. Firstly, a small sample size (65 participants) had been examined from an SME beverage company located in Greece. Accordingly, practical evidence from various industries, nationally and internationally, need to be gathered to establish an enriched and integrated theoretical foundation, which will be treated as an updated version of the proposed conceptual framework. As mentioned earlier, the type of industry, as well as the place where an enterprise is situated, are significant factors when selecting the appropriate digital technology [1]. Secondly, the primary data collected in this study are susceptible to being biased due to the human's involvement in the decision-making process. This can be enhanced by additionally utilizing secondary data and implementing other more advanced and objective prescriptive analytics techniques in the future. Thirdly, the selection process of the involved criteria was based on the most prevalent patterns emerged from relevant literature; although other criteria/factors may affect the digital technology selection in CSCM, this study limits itself to profit, innovation, sustainability, and optimisation as the most significant ones. Besides, it considers equal weights for the criteria involved in the evaluation of each factor without emphasizing the criticality of some of them in the decision-making process. Finally, we acknowledge that sensitivity analysis could be a useful tool for assessing potential differences among the four digital technologies. However, a concrete approach for enhanced transparency from operational research specialists and policymakers' side has been followed to ensure higher implication rates of this methodology in the industrial sector.

6.2. Future research directions

Future research should focus on assessing the differences between fuzzy TOPSIS and VIKOR distance-based methods [123] with respect to the adaptation of new digital technologies in a CSCM context. In addition, taking into consideration the acquired factors from the PCA analysis and the subjectivity in human judgement, confirmatory factor analysis Raji [124] can be applied in the near future. More precisely, the acquired factors can be validated from another sample of the same enterprise. Moreover, to ensure a more objective methodological approach, fuzzy TOPSIS (qualitative data evaluation) could be combined with other well-established optimisation-based management science approaches, such as the Data Envelopment Analysis (quantitative data evaluation) under a CE prism. Additional digital technologies, supported by Industry 4.0, could be considered to ensure a wider spectrum during the selection process. For instance, additive manufacturing could be involved in the benchmarking process to implement the 3 R principles [125]. Cloud computing and virtual or augmented reality are other technologies which could facilitate the transition towards CE implementation. However, due to their limited usage in the Greek territory, they have yet to be considered [55].

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

1. Please respond to the following question by checking (✓) **ONE** box per line. The measurement instrument of this question is a seven-point scale. It ranges from Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H) and Very High (VH).

Criteria	VL	L	ML	M	MH	H	VH
Profit (C1)							
Innovation (C2)							
Sustainability (C3)							
Optimisation (C4)							

2. Please respond to the following questions by checking (✓) **ONE** box per line. The measurement instrument of this question is a seven-point scale. It ranges from Very Poor (VP), Poor (P), Medium Poor (MP), Fair (F), Medium Good (MG), Good (G) and Very Good (VG).

Alternatives/Benefits	**Profit** (C1) VP	P	MP	F	MG	G	VG
Continuous reporting on the status of materials that make up the product.							
Improved warehouse and logistics management							
Optimal production plans							
Evaluation of the performance of various operations within the production systems							
Self-driven and data-driven autonomous decision systems							
Cloud-based interpretation of the available manufacturing resources							
Advanced forecasting techniques to ensure efficient production line operation							
	Innovation (C2)						
Alternatives/Benefits	VP	P	MP	F	MG	G	VG
Continuous reporting on the status of materials that make up the product.							
Improved warehouse and logistics management							
Optimal production plans							
Evaluation of the performance of various operations within the production systems							
Self-driven and data-driven autonomous decision systems							
Cloud-based interpretation of the available manufacturing resources							
Advanced forecasting techniques to ensure efficient production line operation							
	Sustainability (C3)						
Alternatives/Benefits	VP	P	MP	F	MG	G	VG
Continuous reporting on the status of materials that make up the product.							
Improved warehouse and logistics management							
Optimal production plans							
Evaluation of the performance of various operations within the production systems							
Self-driven and data-driven autonomous decision systems							
Cloud-based interpretation of the available manufacturing resources							
Advanced forecasting techniques to ensure efficient production line operation							
	Optimisation (C4)						
Alternatives/Benefits	VP	P	MP	F	MG	G	VG
Continuous reporting on the status of materials that make up the product.							
Improved warehouse and logistics management							
Optimal production plans							
Evaluation of the performance of various operations within the production systems							
Self-driven and data-driven autonomous decision systems							
Cloud-based interpretation of the available manufacturing resources							
Advanced forecasting techniques to ensure efficient production line operation							

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