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Enhancing food supply chain sustainability: exploring the role of IoT enablers and sustainable development goals

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ABSTRACT

The supply chain has emerged as a crucial component of success in the modern global economy, and companies are searching for methods to enhance their supply chain procedures to maintain an advantage over rivals. One of the significant issues that has garnered a lot of attention is the Sustainable Supply Chain (SSC), which drives industries toward sustainability while also boosting organizational productivity. In the same vein, the Internet of Things (IoT) is an emerging technology that enhances intricate supply chain operations. Although many studies conducted in this field have examined the impact of IoT on the supply chain management, very few studies have examined the enablers of IoT in SSC. Therefore, this study aims to fill this gap by evaluating the enablers of IoT in the sustainability of food supply chains. To achieve this goal, the enablers of IoT in SSC are first extracted through a Systematic Literature Review (SLR). Then, using Bayesian Best-Worst Method (BBWM), the importance of each enabler is obtained. According to this method, IoT-based infrastructure is the most important enabler in the economic dimension. Waste management and consumer protection are also the most important in the environmental and social dimensions, respectively. In the end, the alternatives are ranked using TODIM method. The results show that waste management plays an important role in the SSC based on the IoT. The goals of IoT enablers in SSC are also aligned with Sustainable Development Goals (SDGs) (e.g., clean energy, responsible consumption, healthy living, and protecting the planet).

1. Introduction

In recent years, attention has been paid to the environmental, social and economic dimensions of the organizational activities [89], and production and service organizations should consider these dimensions in planning their strategic goals [26]. Therefore, these dimensions have been increasingly integrated with the supply chains and in recent years a new concept known as supply chain sustainability has emerged in operations management [41]. Since the supply chain covers the product stages from processing of raw materials to delivery to the customer, focusing on Sustainable Supply Chain (SSC) will be a step towards achieving production goals [133]. Paying attention to SSC has led to changes in production policies, and it has forced both organizations and researchers to take measures to improve the sustainability. Organizations regard SSC as a key factor influencing product and service quality, the effective delivery of social services, and the responsible utilization of renewable resources. Consequently, they strive to align their objectives and strategies to enhance sustainability [10].

In SSC, the profits and losses of organizations are measured by considering economic, social and environmental aspects of their activities [96]. In other words, sustainability reduces the harmful effects of a business on people, society, and environment, while increasing the value for customers and stakeholders [100]. On the other hand, the desire of consumers to buy sustainable products is increasing, and as a result, SSC has a positive effect on the demand for products. In other words, increasing SSC leads to an increase in customers' willingness to buy the products [130].

Sustainability combines the objectives of organizations across social, environmental, and economic aspects, fostering efficient coordination within the organization's internal processes[13]. SSC is achieved

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through adopting environmentally friendly strategies and taking social responsibility. Consequently, giving due consideration to SSC can lead to the reduction of negative environmental and social impacts, while simultaneously enhancing economic profitability. The advent of new technologies and significant shifts in global markets have heightened the urgency of focusing on SSC. This compels various organizations to enhance their SSC practices to establish or sustain their competitive edge. However, emerging technologies have not been widely and sufficiently used to improve the sustainability of processes and supply chains [45].

Internet of Things (IoT) is an emerging technology that has provided many business opportunities in industry and production and has led to the reconstruction of the entire supply chain [3]. Within the realm of supply chain management, the IoT is characterized as a system of tangible entities equipped with digital sensors, enabling them to sense, monitor, and engage either within individual organizations or across multiple entities. By interlinking the supply chains of various organizations, IoT promotes agility, enhances visibility, facilitates tracking, and fosters information sharing. These capabilities, in turn, expedite the efficient planning, control, and coordination of supply chain operations. In addition, IoT provides tools to improve operational efficiency and organizations can use these tools to ensure the proper performance of their activities and maintain their competitive advantages. By using IoT, organizations can observe information flows, provide significant improvements for all stages of the supply chain, and facilitate inter-organizational and intra-organizational communications [108]. The IoT elevates the extent of information exchange within the supply chain, enhances the transparency of the product life cycle, and streamlines the acquisition of fresh data, ultimately bolstering real-time decision-making capabilities. As a result, IoT assumes a pivotal role in SSC practices [45].

Since IoT facilitates the collection and sharing of supply chain information [124], it can be used to improve the sustainability of the food supply chain. Food security is highly dependent on environmental conditions, and in recent years, the world has faced many extreme weather events caused by global warming. Frequent occurrence of such events can disrupt food security, and extreme climate changes can potentially negatively impact food production, access, and consumption. The idea of using IoT to design and implement a sustainable food security system has attracted the attention of many researchers and policymakers. The use of this technology leads to the minimization of food wastage and the optimization of distribution networks. IoT enables the access and sharing of information for food tracking and significantly contributes to the sustainability of the food security system [61]. IoT has the potential to reduce uncertainties in food quality and reduce resource wastage in various stages of the food supply chain, and ultimately has the ability to prevent food safety incidents. Receiving timely information about the food safety conditions is an effective way to achieve sustainability in the food supply chain, because food quality is the most important factor in the sustainability of a food supply chain [124].

The importance of IoT in SSC has been clearly identified, but few studies have been conducted in this field. For instance, Taiwo et al. [119] assessed stakeholders' perspectives on the applicability of artificial intelligence and machine learning to agriculture. Furthermore, Ajagbe et al. [6] combined deep learning techniques with IoT to provide various solutions that lead to the detection of the COVID-19 pandemic. Earlier, Ajagbe et al. [5] explored the concept of cybersecurity in logistics and supply chain management. In addition, Prajapati et al. [102] proposed a framework for IoT-based SSC by formulating a mixed integer nonlinear programming (MINLP) model. Aliahmadi et al. [10] investigated the development of sustainable processes in organizations using IoT and artificial intelligence. Lamberty and Kreyenschmidt [72] presented an overview of the use of IoT-enabled sensor and communication technologies for monitoring the quality and spoilage of fresh fruits and vegetables. Ghahremani-Nahr et al. [45] explored the potential possibilities afforded by IoT in establishing a SSC. Rejeb et al. [107] studied the potentials and challenges of IoT in the halal food supply chain. Yadav et al. [128] modeled a multilayer system for SSC of agricultural products using IoT.

The literature review found that studies have been conducted to examine the IoT in SSC; however, there is a fundamental gap in this area. Since the study of the enablers of the IoT in all three dimensions of sustainability has not been conducted, there is no coherent and clear classification of the enablers of this smart technology in the economic, social, and environmental dimensions. The IoT as an emerging technology have numerous functions in SSC. On the other hand, researchers have focused on SSC as a new and effective topic. Identifying and classifying the enablers of the IoT in all three dimensions of SSC will increase the efficiency and effectiveness of the supply chain and achieve Sustainable Development Goals (SDGs) in organizations. In this way, capital loss can be prevented, and food industries can prevent the wastage and spoilage of their products. Therefore, to fill this gap, this study evaluates the enablers of the IoT on SSC. To achieve this goal, (i) using a Systematic Literature Review (SLR), IoT enablers are extracted in all three dimensions: economic, social, and environmental, (ii) the Bayesian Best-Worst Method (BBWM) is utilized to determine the importance of each enabler, and (iii) employing the TODIM (TOmada de Decisao Interativa Multicriterio) method, four food supply chains are ranked based on the enablers. Hence, the questions of this study are designed as follows.

RQ1. What are the enablers of the IoT in SSC?

RQ2. What is the importance of each enabler and how do they impact the case study analyzed in this research?

RQ3. How do IoT enablers contribute to the achievement of SDGs?

This study makes a unique contribution in the theoretical aspect by examining the enablers of the IoT in the three dimensions of the supply chain: economic, social, and environmental. This research extends the literature on IoT-based SSC in digital transformation and provides new insights in this field. Also, by examining the relationship between IoT enablers and the SDGs, this research contributes to their promotion. Furthermore, by hybridizing the BBWM-TODIM, the organizations studied were ranked in a standardized and systematic way based on IoT enablers. From a practical perspective, this study introduces IoT enablers as a tool to increase sustainability in the food industry. This enables managers in developing economies to increase the sustainability of their supply chains based on technological resources and seek to gain a competitive advantage and outperform their competitors globally.

The rest of the paper is organized as follows. Section 2 presents the theoretical foundations of SSC, discusses the application of the IoT, and reviews relevant research in this field. Section 3 introduces the BBWM, a decision-making approach developed by Mohammadi and Rezaei [86], which provides more reliable results while requiring fewer pairwise comparisons than other methods. This technique is used in this study to analyze the identified enablers, followed by the ranking of four dairy product manufacturers using the TODIM method. Section 4 presents the results, while Section 5 provides the discussion and conclusions.

2. Literature review

In this section, the theoretical background of supply chain management, supply chain sustainability, and the IoT is initially discussed, reviewing multiple studies along with their features. Subsequently, the application of the IoT in supply chain sustainability is examined, and previous studies in the research area of IoT and SSC are compared and reviewed. Finally, considering the Systematic Literature Review (SLR) and expert opinions, the enablers of IoT in enhancing sustainability in the supply chain are identified and introduced.

2.1. Theoretical background

2.1.1. Supply chain management

In today's competitive environment where customer expectations are increasing and the life cycle of products is getting shorter, the importance of supply chain management has increased. Supply chain management was introduced in the early 1980s by practitioners and consultants in the United States of America, and it was used for organizational planning and transfer of information [87]. Over time, supply chain management expanded and led to the integration of all physical and information flows in organizations [120]. This integration has made it possible for suppliers, manufacturers, distributors and sellers to connect to each other in a chain and to improve the production and delivery of the final product to the customer by exchanging information with each other. The supply chain has three main stages: logistics, production, and distribution. Activities related to raw materials take place in logistics stage and the final product is delivered to consumers in the distribution phase. At each stage of the supply chain, there are several actors that affect the product and sales and the structure of the supply chain [28].

The supply chain plays an important role in industries and the main goal of the supply chain is to balance supply and demand and ultimately reduce production costs and increase customer satisfaction. Proper supply chain management connects all physical and informational factors and increases the effectiveness and efficiency of organizations. Among the factors that play important roles in the effectiveness of the supply chain, we can mention material flow management, coordination factors, stakeholder factors, and interface&value factors. Material flow management refers to the control and coordination of physical flows of materials that include packaging, transportation, storage, etc. Coordination factors refer to factors that coordinate units inside and outside the company and as a result, help to implement the organization's strategies and supply chain optimization. Stakeholder factors include the relationships that exist between partners in the supply chain. These relationships play important roles in the development of processes from production to consumption and rely on three elements: standardization, communication, and quality. Interface&value factors refer to the management of relationships between units to create a value chain and improve the productivity of production line [120].

Research in the field of supply chain has increased greatly over time. The realm of supply chain management has expanded even beyond production lines and is also used in economic and social management [51]. Due to the existence of various branches in the supply chain, this area has been divided into various sub-areas: green supply chain [9,42,44,74,115], resilient supply chain [4,9,103,131], lean and agile supply chain [91,94,97,98], and supply chain 4.0 or digital supply chain [80,113,116,133] which is the smart form of the supply chain. The SSC [10,22,38,88,116] is also one of the sub-areas of the supply chain, which will be discussed in this article.

2.1.2. *Supply chain sustainability*

In the contemporary business landscape, the capacity for supply chain sustainability has emerged as a vital organizational competency. It impacts an organization's supply chain and logistics network by encompassing environmental considerations and efficient waste management across the entire supply chain lifecycle, starting from raw material procurement to product design and development[67]. Broadly speaking, sustainability emphasizes effectiveness, and organizations incorporate sustainability strategies across all supply chain functions, spanning from sourcing materials and product design to manufacturing, warehousing, and distribution. It may also include other aspects such as green warehousing, green construction supplier evaluation, selection of green suppliers, environmental protection, sustainable public transportation, and logistics optimization that are enablers of SSC [64,65,93]. Sustainability integrates processes such as product design, production, distribution and restructuring processes that exist at the core of the supply chain [46]. With increasing attention and desire of consumers towards supplier sustainability, uncoordinated supply chains gradually move towards coordination, which increases cooperation between supply chain members [130]. Sustainable Supply Chain (SSC) management is equally crucial for the organization to establish competitive edges in areas such as cost-effectiveness, product quality, dependability, adaptability, and responsiveness[45]. Concerns raised by governmental and non-profit entities, environmental advocates, and the general populace regarding issues like global warming, the depletion of natural resources, overreliance on non-renewable resources, and the heightened industrialization in developed and emerging economies have prompted various stakeholders to shift their focus toward sustainable business practices. Consequently, organizational, social, and environmental responsibility has evolved into a key objective for both production and service-oriented enterprises. Additionally, a multitude of external and internal factors have spurred organizations, particularly in the upstream segments of the supply chain, to embrace sustainable supply chain management. External factors encompass legal mandates, the specific nature of the business, competitive pressures, and the interests of shareholders. Internally, the perspectives of top management, incentives for sustainable suppliers, and evolving customer preferences have all contributed to this shift [11].

The benefits of implementing a SSC encompass enhanced customer satisfaction, heightened quality, increased innovation, greater trust, improved flexibility, better cost management, and optimized inventory levels. As the environmental impact of human actions continues to grow, the notion of sustainability has assumed paramount significance for organizations, governments, individuals, and notably, environmental advocates. Conversely, emerging technologies have the potential to bolster product life cycles, operational and system efficiency, sustainability monitoring and reporting, and the promotion of environmentally responsible practices[45].

2.1.3. *Internet of things*

IoT has changed the world and these changes will increase in the future. IoT is a system that connects physical and virtual things. Using the real-time information produced by IoT, the environment can be remotely monitored, predicted, modified, and controlled [49]. IoT has devices with the ability to share information and data in the network without the need for human-computer or human-human interactions [18]. Using concepts such as blockchain, artificial intelligence, and big data, IoT provides an ecosystem for the use of all web-based smart devices and sensors. One of the applications of blockchain in IoT is privacy protection [138]. The application of artificial intelligence in IoT enables energy sustainability [29]. Big data is used in IoT to analyze, process, and share information [18].

IoT can remotely connect multiple devices to each other and enable them to be turned on and off through the web and also enable the use of software and automation processes for smart applications. Hence, within the supply chain context, IoT can be described as a system of tangible entities equipped with digital sensors, allowing them to digitally perceive, monitor, and engage, either within an organization or between an organization and its supply chain partners. This facilitates real-time agility, visibility, tracking, and information sharing [108]. The literature review shows that IoT plays important roles in the supply chain and increases its effectiveness. IoT makes the supply chain transparent and makes it more agile against risks. Also, IoT helps to improve risk management and increases the efficiency of risk management in the supply chain. Another application of IoT is to increase the effectiveness of operations in the warehousing and logistics sector of the supply chain [31]. Table 1 lists some of the studies relevanted in this field, by contribution, method, and area of study.

2.2. *Application of the Internet of Things in supply chain sustainability*

The expansion of the needs of people and societies has created serious challenges for different aspects of life. Today, supply chains operate in an environment that is increasingly complex and dynamic. In such an environment, it is inevitable to have an appropriate SSC to respond to the drastic changes in customer needs. It is obvious that organizations active in the supply chain field should accelerate their

Table 1
Relevant researches overview.

Scholar (s)	Contribution	Methodology		Area of study	
		Qualitative	Quantitative	IoT	SC
[63]	Examining the supply chain based on the IoT from the perspective of decision support systems	LR		✓	✓
[15]	Investigating the Hierarchical Impact of IoT Capability on Supply Chain Integration in the Retail Industry	LR- Online survey	SEM	✓	✓
[79]	Presenting a scheme based on the IoT in a farm network to increase the productivity of agricultural supply chains	LR		✓	✓
[134]	Improving the competitiveness of the financing chain of small and medium companies based on the IoT	LR	BPNN	✓	✓
[7]	Investigating the visibility of the supply chain and its operational performance based on IoT and big data analysis	LR	Covariance-based SEM	✓	✓
[31]	Examining the characteristics of pharmaceutical supply chain based on IoT and Blockchain	LR- Semi-structured interviews		✓	✓
[16]	Providing intelligent supply chain monitoring model in operations management platform		Intelligent supervision system	✓	✓
[3]	Analysis of existing literature for the integration of IoT applications in the supply chain	SLR		✓	✓
[62]	Examining the roles of IoT in the supply chain	LR and Bibliometric Analysis		✓	✓
[19]	Examining the impact of IoT on supply chain management	Bibliometric analysis of the literature		✓	✓
[57]	Presenting a leather bullwhip effect simulation model based on IoT		Mathematical model of the bullwhip effect	✓	✓
[59]	Examining the barriers to adopting the IoT in the retail supply chain	LR	ISM and DEMATEL	✓	✓
[52]	Providing blockchain-based IoT software architecture to replace the third-party present in the food supply chain	LR		✓	✓
[105]	Investigating the deployment of blockchain and IoT in modern supply chains and extracting six research propositions based on blockchain and the key features of IoT	Narrative LR		✓	✓

(SC) Supply chain, (LR) Literature review, (SEM) Structural Equation Modeling, (SLR) Systematic literature Review research, (BPNN) Proposed Back Propagation Neural Network, (ISM) Interpretive Structural Modelling, (DEMATEL) Decision Making Trial and Evaluation Laboratory.

movement towards sustainability and use technologies such as IoT to create sustainable processes. A supply chain based on IoT provides a better guarantee for human rights and fair work by receiving accurate information from various sources. Also, smart contracts may be able to automatically establish regulatory rules and policies in order to track and control the sustainability of activities and promote or manage appropriate reforms [45].

IoT has a positive and significant effect on the integration of internal processes and the affairs of customers and suppliers, and as a result, it has a positive effect on the performance of the supply chain as well as the sustainability of the organization [34]. The applications of IoT in SSC are as follows [27]:

- Reducing product re-design and re-structuring by identifying product capabilities.
- Facilitating the actual tracking of the products and determining the amount of financial factors.
- Promoting product recycling by encouraging individuals to actively engage in recycling initiatives.
- Improving the efficiency of trading plans.

IoT, which is one of the crucial sources for producing big data and artificial intelligence, can analyze patterns between raw data and various phenomena and help consumers make optimal decisions [25]. Smart monitoring of the supply chain can include providing early warning at the time of delivery of goods in the warehouse, during transportation, and during processing. Recent developments have improved supply chain monitoring methods and operational efficiency, reduced various external risks, and provided a reference for supply chain activities [16]. Leveraging IoT to enhance the digital supply chain can empower the organization to enhance the accuracy of information transmission, diminish the potential for information imbalances during e-commerce transactions, and swiftly and effortlessly adapt to abrupt shifts in market dynamics and environmental factors [136].

The supply chain has a direct and great impact on the social, environmental, and economic aspects of organizations. With the proper use of the latest technologies, SSC can be improved. By using IoT technology, it is possible to reduce greenhouse gas emissions, reduce the consumption of diesel and gasoline of cargo vehicles by optimizing routes, prevent financial damage and theft by increasing the reliability of transactions, reduce the risks, and improve the safety of workers [118]. A competitive supply chain requires a careful combination of multiple suppliers, especially when dealing with social, environmental and economic sustainability of activities. As an example, the outbreak of Corona has endangered the supply chain of agricultural and food products globally and has caused disruptions in the logistics network and prediction of demands. These challenges can be addressed using the IoT technology [128].

IoT facilitates the use of connected devices, sensors, and technologies, and thereby enables the coordination, monitoring, and optimization of supply chain processes and enables the creation of innovative methods in the food supply chain to address consumer concerns [107]. IoT can provide product provenance information (information that links a product to its origin) in the food supply chain and help consumers choose the products that best suit their needs. Also, IoT makes it possible for managers of warehouses to manage their inventory more effectively so that they can monitor the duration of storage of any particular product or package and make appropriate decisions for it [52].

IoT can distribute information throughout the food supply chain more effectively and efficiently [82]. This technology empowers the food industry to enhance decision-making when dealing with perishable goods, unpredictable shifts in supply, and compliance with food safety and sustainability standards by virtualizing operational management procedures. Virtualization allows supply chain participants to remotely and instantaneously monitor, oversee, plan, and optimize processes using virtual entities on the Internet, eliminating the need for physical on-site presence [122]. IoT has performed well in minimizing food wastage by enabling various methods such as the use of smart waste systems, smart refrigerators, etc. [71].

According to the literature, IoT has useful applications in industries, and industries are moving towards the use of this technology. Few studies have been conducted on the application of IoT in SSC, and most of the studies related to this field are focused on applications, opportunities, and the threats of IoT in the supply chain. Also, there are very few researches that have used decision-making techniques in this field. The studies carried out in this field are summarized in Table 2 by contribution, method, and area of study.

2.3. IoT enablers in increasing supply chain sustainability

It was found that IoT can make SSC effective and prevent food waste and spoilage. However, few efforts have been conducted to identify IoT enablers in all three dimensions of sustainability in the supply chain and most researchers have investigated the potential, opportunities, and threats of IoT in the supply chain. Therefore, in order for IoT to be effective in SSC, their enablers must first be identified. If they are not recognized, SSC will not be efficient and effective and will also cause a waste of capital and resources, and for this reason, identifying these enablers is essential. Hence, this study identifies and categorizes IoT enablers so that managers can increase their understanding of them and adopt appropriate strategies to increase supply chain sustainability.

In this study, SLR is utilized to identify the enablers. This approach systematically extracts papers through transparent steps and leads to the development of literature and knowledge in the field of study [14]. Furthermore, this approach is popular among researchers and has been widely used in supply chain management and logistics (e.g. Hamid et al. [50]; Acharjya and Dash [2]; Hasan et al. [53]). This study employed the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol presented by Paul et al. [99]. This protocol leads to the presentation of quality results with concise and transparent steps and does not have the challenges of data collection in the traditional SLR approach.

According to the SPAR-4-SLR protocol, the enablers are extracted in three main steps and six sub-steps. The assembling is the first main step of this protocol and includes two sub-steps of identification and acquisition. In the identification step, the scope of the study, research questions, and source type are determined. The scope of this study is the IoT and SSC. The research questions are also related to the study of IoT enablers and their impact on increasing supply chain sustainability. In this study, only journal papers are considered. In the acquisition step, a search was conducted in Scopus and Web of Science databases. Although there are other reliable databases, increasing the number of databases increases the amount of duplicate data. The search was performed based

Table 2
Relevant researches overview.

Scholar (s)	Contribution	Methodology		Area of study	
		Qualitative	Quantitative	IoT	SSC
[81]	Investigating the adoption of the IoT on the sustainability of the renewable energy supply chain and providing a conceptual framework	Standard questionnaire	SEM	✓	✓
[12]	Strategy selection for sustainable supply chain systems based on the IoT	LR	DPFS-CODAS	✓	✓
[38]	Investigating the impact of Industry 4.0 technologies on the SSC and the impact of this technology on the forward and reverse supply chain	SLR		✓	✓
[88]	Development of a supply chain network in the time of Covid-19 based on the IoT, taking into account the dimensions of sustainability		Simulation	✓	✓
[22]	Analyzing the effects of IoT on SSC and testing supply chain dynamics as a moderator	Structured questionnaire	SEM	✓	✓
[116]	Investigating the features of Industry 4.0 technologies and their impact in guiding sustainability values.	SLR		✓	✓
[10]	Creating stable processes in the organization based on the IoT and artificial intelligence	LR		✓	✓
[66]	Examining the benefits of IoT-based supply chain system	LR		✓	✓
[45]	Exploring the potential of IoT to create a SSC	LR		✓	✓
[102]	Creating a framework for a SSC based on the IoT to provide textile items using a business-to-business model		MINLP	✓	✓
[128]	Modeling the multi-layer system based on the SSC of agricultural products through IoT technology	LR	ISM and F-DEMATEL	✓	✓
[107]	Investigating the potentials and	SLR		✓	✓

(continued on next page)

Table 2 (*continued*)

Scholar (s)	Contribution	Methodology		Area of study	
		Qualitative	Quantitative	IoT	SSC
	challenges of IoT in the halal food supply chain				
[61]	Modeling sustainable food security system based on IoT	LR	F-TISM	✓	✓
[121]	Simulating the supply chain without the use of new technologies and comparing it to when incorporating IoT, RFID, and Blockchain technology in the supply chain.	Exploratory analysis based on simulation		✓	✓
[21]	Exploring the potential, challenges, and impact of IoT and other powerful technologies like blockchain on the quality of the food supply chain	Structured bibliometric and network		✓	✓
[108]	Review of IoT bibliography in supply chain management	Bibliometric analysis		✓	✓
[127]	Development of an efficient and supportive coordination system based on the IoT to strengthen the coordination mechanism in the management of the agricultural food supply chain in the context of a pandemic	LR	DEMATEL and ISM	✓	✓
[78]	Investigating various aspects of SCM, ERP, IoT and identifying potential opportunities for SSC based on IoT	LR		✓	✓
[1]	Creating a smart and secure supply chain system based on the IoT	LR	AHP and N-DEMATEL	✓	✓
[122]	Analyzing the concept of the virtual food supply chain from the perspective of IoT and presenting an architecture for the implementation of powerful information systems	LR		✓	✓

(SSC) Sustainable supply chain, (LR) Literature review, (SLR) Systematic literature Review research, (CODAS) Combinative Distance based Assessment, (SEM) Structural Equation Modeling, (DPFSs) Decomposed Pythagorean Fuzzy Sets, (MINLP) Mixed Integer Nonlinear Programming, (F) Fuzzy, (TISM) Total Interpretive Structural Modelling, (AHP) Analytic Hierarchy Process, (N-DEMATEL) Neutrosophic-Decision Making Trial and Evaluation Laboratory.

on the title, abstract, and keywords and was conducted from 2016 to 2024. Finally, 58 papers were found and were examined in the second step.

In the second step (arranging), the papers extracted in the previous step are organized and purified. In the organization, the papers are examined from the perspective of the scope of the study and keywords. Since the scope of the study was business, management, and accounting, four papers were outside these field and had keywords unrelated to the research topic, and were removed. In the purification, the document type and language filter were applied. The number of conference papers, book chapters, and editorial papers was 7 and they were eliminated. In this way, only journal papers remained. Also, 4 papers were non-English and were deleted at this stage. By removing duplicate data, a total of 34 papers remained and were evaluated in the next stage.

The last step of the SPAR-4-SLR protocol is assessing, which includes evaluation and reporting. Excel software was used to evaluate 34 papers. They were categorized and analyzed in this software and shown in Tables 1 and 2. By analyzing these papers and using the opinions of experts active in the area of IoT and SSC, the enablers of the IoT in SSC were extracted and reported in Table 3. It is important to note that the identified enablers of the IoT in enhancing the sustainability of the supply chain have been categorized into three dimensions—economic, environmental, and social—based on the SLR, expert opinions from the studied industry, and the existing infrastructure. Therefore, these enablers may require adaptation based on the specific country, industry, available infrastructure, and defined objectives. As shown in Table 3, the proposed model and classification presented in this study should be considered as a preliminary framework rather than a definitive structure.

3. Research methodology

Improving supply chain performance requires solving multi-criteria decision-making problems and identifying different factors which are called evaluation criteria. Therefore, the use of existing methods of solving multi-criteria problems can be helpfull to improve supply chain performance. In the present study, we developed our method using field study and literature review. The method has three phases (Fig. 1): identification, selection, and analysis.

Identification phase. The enablers of IoT in SSC were identified by reviewing the studies conducted in this field from 2016 to 2023, and a total of 15 enablers were extracted and listed. Considering these enablers, 7 experts who had the following qualifications were invited to participate in the study: 1) familiar with the concept of IoT; 2) at least 5 years of experience in the field of IoT and SSC; 3) having at least a master degree in industrial management, industrial engineering and similar fields, and 4) willing to participate in the research and completing questionnaires. The profile of experts involved in the decision-making processes of this study is presented in Table 4.

Selection phase. After identifying the enablers of IoT in SSC and selecting 7 experts in the field of IoT and SSC, a questionnaire related to the BBWM was designed and sent to the experts. Before sending the questionnaire, an explanation meeting was held for the experts and the purpose of the research and how to complete the questionnaires were explained to them.

After completing the questionnaires by the experts, the BBWM was implemented in MATLAB software. The BWM, which was introduced by Jafar Rezaei in 2015, is one of the new decision-making techniques. In this method, the best and worst criteria are determined by the experts, and the rest of the criteria are compared with these two criteria in a pairwise manner. Then a minimum-maximum (MINMAX) problem is solved to determine the weights of the criteria. This method has fewer pairwise comparisons than other decision-making methods and provides more reliable solutions. The steps of this method are as follows [109]:

Step 1: identifying the criteria

Step 2: determining the best and worst criteria

Table 3
List of IoTs enablers in SSC.

Dimensions of SSC	Enablers	Brief Definition	Reference(s)
Economic (C_1)	Creating the IoT infrastructure (C_{11})	Creating the IoT infrastructure for the stability of the supply chain	Kayvanfar et al. [63], Yadav et al. [128], Yadav et al. [127], Rejeb et al. [105], Kamble et al. [58], and Kaur [61]
	Blockchain (C_{12})	Creating integrity, security, tracking and transparency of the supply chain and eliminating the shortcomings of the IoT	Dutta et al. [38], Aliahmadi et al. [10], Ghahremani-Nahr et al. [45], Malik et al. [77], Malik et al. [77], Rejeb et al. [107], Yadav et al. [128], Kaur [61], Rejeb et al. [105], and Haroon et al. [52]
	Big data (C_{13})	Big data from the IoT and its analysis to order the desired product of the consumer	X. Chen et al. [31], Al-Khatib [7], Aliahmadi et al. [10], Yadav et al. [128], Koot et al. [69], Ahmed et al. [3], Yadav et al. [127], Rejeb et al. [108], Kodan et al. [68], Jiang [57], Kaur [61], and Rejeb et al. [105]
	Information sharing (C_{14})	Information sharing is a prerequisite for the exchange of opinions between different sub-suppliers of a multi-layered system that takes place through the IoT.	Masoomi et al. [81], Ahmed et al. [3], Yadav et al. [128], Yadav et al. [127], Rejeb et al. [108], Kaur [61], Rejeb et al. [105], and Ben-Daya et al. [20]
	Artificial inteligence (C_{15})	To analyze big data and predict consumer demand	Aliahmadi et al. [10], Aliahmadi et al. [10], Kaya et al. [62], Ben-Daya et al. [21], and Kaur [61]
	Third-party logistics provider (C_{16})	Third-party logistics (3PL) service providers for logistics activities such as proper tracking of perishable products during transit	Bai et al. [16], Ghahremani-Nahr et al. [45], Yadav et al. [128], Malik et al. [77], Rejeb et al. [107], and Yadav et al. [127]
	Route optimization (C_{17})	Optimizing the route for consumers as well as for distribution abroad	Billah et al. [22], Yadav et al. [128] and Ben-Daya et al. [20]
	RFID (C_{18})	In order to identify and track products, collect data identified by sensors and provide consumers access to product information	Aliahmadi et al. [10], Maulana et al. [82], Yadav et al. [128], Ahmed et al. [3], Yadav et al. [127], Rejeb et al. [108], Kaya et al. [62], Kodan et al. [68], Ben-Daya et al. [21], Bouzembrak et al. [24], Jiang [57], Ben-Daya et al. [20], Haroon et al. [52], Rejeb et al. [105], and Verdouw et al. [122]
Environmental (C_2)	Cold chain (C_{21})	Development of IoT-based cold chain for perishable products	Aliahmadi et al. [10], Yadav et al. [128], Rejeb et al. [107], Ben-Daya et al. [21], Rejeb et al. [105], Bouzembrak et al. [24], and Verdouw et al. [122]
	Waste management (C_{22})	Waste management and recycling through IoT applications	Mosallanezhad et al. [88] and Paul et al. [100]
	Green design and green production (C_{23})	Green design and green production in the context of the IoT for the sustainability of the supply chain in the environmental dimension	Srhir et al. [116] and Luthra et al. [76]
Social (C_3)	Simulation of consumption pattern (C_{31})	Simulation-based big data analytics to meet global consumer demand through the IoT	Yadav et al. [128] and Kaur [61]
	Consumer protection (C_{32})	Supporting consumers to customize products according to consumers' needs	Paul et al. [100], Kaya et al. [62], and Ben-Daya et al. [21]
	Providing training programs to suppliers and vendors (C_{33})	Training on the implementation of special projects and performance monitoring for the sustainability of the supply chain	Alkan snd Kahraman [12], Mane et al. [79] and Paul et al. [100]
	Government policies (C_{34})	Government policy in line with the adoption of the IoT and helping to implement it for the stability of the supply chain	Yadav et al. [128], Kaur [61], Rejeb et al. [105], and Luthra et al. [76]

Step 3: Comparing the best criterion with other criteria and assigning a number from 1 to 9 to each comparison, which yields the Best-to-Others vector.

Step 4: Comparing other criteria with the worst criterion and assigning a number from 1 to 9 to each comparison, which yields the Others-to-Worst vector.

Step 5: calculating the optimal weights $(W_1^*, W_2^*, \ldots, W_n^*)$ using model (1):

$$\min \max_j \left\{ \left| \frac{W_B}{W_j} - a_{Bj} \right|, \left| \frac{W_j}{W_W} - a_{jW} \right| \right\}$$

$$\overset{s.t.}{\sum_j} W_j = 1 \tag{1}$$

$$W_j \geq 0, \ for\ all\ j$$

Model (1) can be converted to model (2):

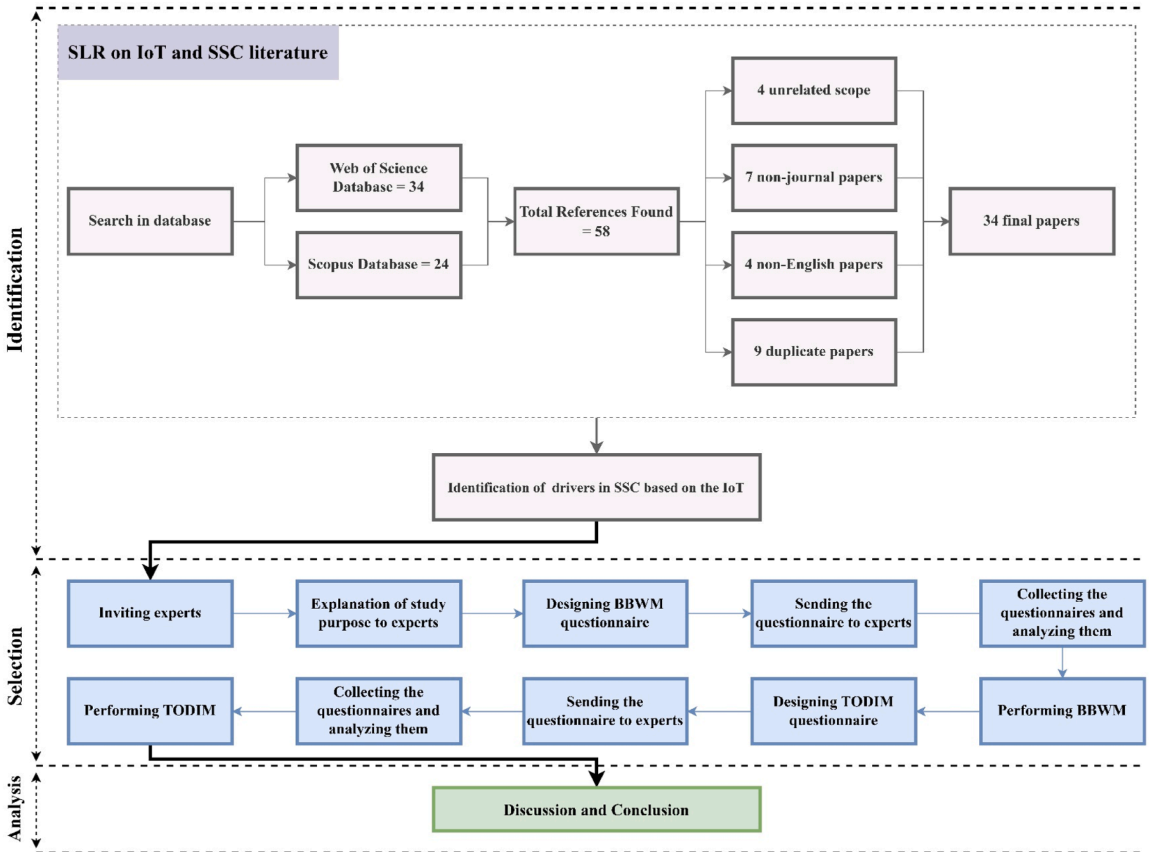

Fig. 1. Methodology of the study.

Table 4
Experts profile.

Expert ID	Gender		Education		Experience	Area	
	F	M	PhD	MA		A	I
E_1		✓	✓		20+		✓
E_2	✓		✓		15+	✓	
E_3		✓		✓	5+	✓	
E_4	✓		✓		20+		✓
E_5	✓			✓	5+		✓
E_6		✓	✓		10+	✓	
E_7		✓		✓	15+	✓	

(F) Female, (M) Male, (MA) MA/MSc/MEng etc., (A) Academic, (I) Industry

$$
\begin{aligned}
& \min \xi \\
& s.t. \\
& \left|\frac{W_B}{W_j} - a_{Bj}\right| \le \xi,\ \text{for all } j \\
& \left|\frac{W_j}{W_W} - a_{jW}\right| \le \xi,\ \text{for all } j \\
& \sum_j W_j = 1 \\
& W_j \ge 0,\ \text{for all } j
\end{aligned} \tag{2}
$$

The optimal weights $(W_1^*, W_2^*, \ldots, W_n^*)$ and the value of ξ^* are obtained from the above relations.

3.1. Bayesian best-worst method

In the BBWM, a Bayesian hierarchical model is used to find the optimal values of a set of criteria. This method is similar to the best-worst method in terms of the questionnaire and the use of experts' opinions, except that it uses the concept of statistical distribution to find the optimal weights. Therefore, in the BBWM, the first four steps of the BWM are followed, and then the optimal weights of the criteria are calculated using statistical distribution. Suppose that in a decision-making problem, K experts *(k=1, ..., K)* evaluate criteria $c_1, \ldots, c_n$ based on the best and worst criteria. $A_B^{1:K}$ and $A_W^{1:K}$ are the best and worst criteria vectors according to K experts' opinions and W^{agg} is the overall optimal weight. The joint probability distribution of group decision is written as follows [86]:

$$P\left(W^{agg}, W^{1:K} \middle| A_B^{1:K}, A_W^{1:K}\right) \tag{3}$$

After calculating the above probability, the probability of each variable is calculated using the following probability rule (x and y are arbitrary random variables):

$$(X) = \sum_y P(x, y) \tag{4}$$

In relations (3) and (4), the group optimal weight W^{agg} depends on each of the optimal weights determined by each expert (W^K), i.e:

$$P\left(A_W^K \middle| W^{agg}, W^K\right) = P\left(A_W^K \middle| W^K\right) \tag{5}$$

By applying the Bayes rule on the joint probability (3), we have:

$$
\begin{aligned}
P\left(W^{agg}, W^{1:K} \middle| A_B^{1:K}, A_W^{1:K}\right) & \propto P\left(A_B^{1:K}, A_W^{1:K} \middle| W^{agg}, W^{1:K}\right) P\left(W^{agg}, W^{1:K}\right) \\
& = P\left(W^{agg}\right) \prod_{k=1}^{k} P\left(A_W^k \middle| W^k\right) P\left(A_B^k \middle| W^k\right) P\left(W^k \middle| W^{agg}\right)
\end{aligned} \tag{6}
$$

Since the estimation of the parameters in equation (6) depends on the estimation of other criteria, a chain is created between different parameters. Existence of the chain is the reason why it is called a hierarchical model. Now the distribution of each element in equation (6) should be specified. The multinomial distribution can be used to model A_B and A_W. Therefore, they can be modeled as follows:

$$A_B^k|W^k \sim multinomial\left(1/W^k\right),\ \forall k = 1,\dots,K, \quad A_W^k|W^k \sim multinomial\left(W^k\right),\ \forall k = 1,\dots,K \tag{7}$$

It is reasonably expected that the value of W^k (for each k) is in the neighborhood of the value of W^{agg}. Therefore, given the value of W^{agg}, Dirichlet distribution is used to model W^k:

$$W^k|W^{agg} \sim Dir(\gamma \times W^{agg}),\ \forall k = 1,\dots,K \tag{8}$$

Since W^{agg} is the mean of the distribution, relation (8) indicates that values of each W^k associated with each expert should be in the neighborhood of W^{agg} and the closeness of the values of W^k to W^{agg} is influenced by the non-negative concentration parameter γ. Also, gamma distribution is used to model the γ parameter (a and b are the shape parameters):

$$\gamma \sim gamma(a, b) \tag{9}$$

Finally, prior distribution of the Bayesian method is applied for W^{agg} using uninformative Dirichlet distribution with $\alpha = 1$:

$$W^{agg} \sim Dir(a) \tag{10}$$

To compute the posterior distribution of the Bayesian method, a Markov-chain Monte Carlo (MCMC) technique is used. Also, relation (6) is used for the MCMC sampling. So, step 5 of BWM is replaced by the Bayesian model. The Bayesian model provides more information about the confidence of the relations between each pair of criteria, which will be explained further below.

3.2. Credal Ranking

Credal Ranking can determine the degree of superiority of criteria over each other. Computing the posterior distribution of the weights can help to determine the confidence of the relations between various criteria. The difference between the credal ranking and other ranking methods is that the credal ranking compute a confidence level based on the Dirichlet distribution of W^{agg}, while other ranking approaches usually try to compute the superiority of two numbers/intervals over each other. To explain the credal ranking, credal ordering should first be defined. The credal ordering O for a pair of criteria C_i and C_j is defined as follows:

$$O = \left(C_i, C_j, R, d\right) \text{ where } R \leq > C_i, C_j,\ \mathrm{d} \in [0, 1] \tag{11}$$

Where $d \in [0, 1]$ represents the confidence of the relation.

The credal ranking for a set of criteria $C=(C_1,C_2,\dots,C_n)$, is a set of credal orderings that includes all pairs $\left(C_i, C_j\right)$ for $C_i, C_j \in C$. In order to assess the consistency of the results, the confidence levels of credal orderings should be calculated. For this purpose, posterior distribution of W^{agg} is used. The confidence level of superiority of c_i over c_j is calculated as:

$$P\left(c_i > c_j\right) = \int I_{\left(W_i^{agg} > W_j^{agg}\right)} P\left(W^{agg}\right) \tag{12}$$

Where $P(W^{agg})$ is the W^{agg} posterior distribution, and I is equal to 1 if $W_i^{aggq} > W_j^{aggq}$ and zero otherwise. By obtaining the samples from the posterior distribution using Markov-chain Monte Carlo technique, the above integration can be approximated and the confidence relation can be rewritten as:

$$P\left(c_i > c_j\right) = \frac{1}{Q}\sum_{q=1}^{Q} I\left(W_i^{agg_q} > W_j^{agg_q}\right) \quad P\left(c_j > c_i\right) = \frac{1}{Q}\sum_{q=1}^{Q} I\left(W_j^{agg_q} > W_i^{agg_q}\right) \tag{13}$$

Where q is the number of samples, W^{aggq} is the qth sample of W^{agg}. Therefore, the superiority of each criterion over one another can be calculated for each pair of criteria. As with the traditional ranking, it is clear that $P\left(c_i > c_j\right) + P\left(c_j > c_i\right) = 1$. Therefore, if $P\left(c_i > c_j\right) > 0.5$ then c_i will be more important than c_j. So, by considering a threshold of 0.5 for the credal ranking, the traditional ranking of criteria is obtainable.

3.3. TODIM method

After obtaining the importance of each enabler, TODIM method was used to rank the alternatives. TODIM, which is a multi-criteria decision-making technique based on the prospect theory, determines the relative advantage of an indicator to other indicators according to the psychological Judgments of experts. The method was first introduced by Brazilian researchers in 1991, and so far, it has been used in various fields [129]. for example, Lin et al. [73] used this technique to assess the risk of excavation system. Zhao et al. [135] used TODIM technique to select network security service providers. Zhang et al. [132] used this technique to select third-party logistics. Alali & Tolga [8] used this technique for portfolio allocation.

In TODIM method, experts assign scores to profit and loss indicators asymmetrically. Compared to other methods, TODIM is simpler, easier and more understandable for experts [8]. The steps of the TODIM method are as follows [40]:

Step 1: normalizing the decision matrix $X = \left[x_{ij}\right]_{m\times n}$ as $Y = \left[y_{ij}\right]_{m\times n}$ using a normalization method.

Step 2: calculating the relative weight of c_j to superior criterion c_r as W_{jr} (relation 14).

$$W_{jr} = W_j / W_r\ j, r \in N \tag{14}$$

Where $W_r = max\left\{W_j | j \epsilon N\right\}$

Step 3: calculating the dominance of the alternative A_i over alternative A_k for each criterion c_j using equation (15):

$$\Phi_j(A_i, A_k) = \begin{cases} \sqrt{\left(y_{ij} - y_{kj}\right) W_{jr} \Big/ \left(\sum_{j=1}^{n} w_{jr}\right)}, & \left(y_{ij} - y_{kj}\right) > 0, \\ 0, & \left(y_{ij} - y_{kj}\right) = 0, \\ \left(-\frac{1}{\theta}\right)\sqrt{\left(y_{kj} - y_{ij}\right)\left(\sum_{j=1}^{n} w_{jr}\right) \Big/ w_{jr}}, & \left(y_{ij} - y_{kj}\right) < 0 \end{cases} \tag{15}$$

Where θ is the attenuation factor of the losses. $y_{ij} - y_{kj}$ denotes the gain of alternative A_i over alternative A_k concerning attribute C_j if $y_{ij} - y_{kj} > 0$ and the loss if $y_{ij} - y_{kj} < 0$.

Step 4: calculating the overall dominance of all alternatives from A_i to A_k using equation (16):

$$\delta(A_i,\ A_k) = \sum_{j=1}^{n} \Phi_j(A_i, A_k),\ i, k \in M. \tag{16}$$

Step 5: calculating the overall score of the A_i using equation (17):

Table 5
Best-to-others and Others-to-worst expert-made pairwise comparisons for the dimensions of SSC.

Expert	Best Dimension	C_1	C_2	C_3	Expert	Worst Dimension	C_1	C_2	C_3
1	C_1	1	4	3	1	C_2	4	1	2
2	C_1	1	2	3	2	C_3	3	2	1
3	C_1	1	3	5	3	C_3	5	4	1
4	C_2	2	1	4	4	C_3	3	4	1
5	C_1	1	6	4	5	C_2	6	1	3
6	C_2	2	1	4	6	C_3	3	4	1
7	C_3	5	3	1	7	C_1	1	4	5

Table 6
Final weights of the SSC dimensions.

Dimensions	Final weights
C_1	0.43
C_2	0.33
C_3	0.24

$$\xi(A_i) = \frac{\sum_{k=1}^{m}\delta(A_i,A_k) - \min_{i\epsilon M}\left\{\sum_{k=1}^{m}\delta(A_i,A_k)\right\}}{\max_{i\epsilon M}\left\{\sum_{k=1}^{m}\delta(A_i,A_k)\right\} - \min_{i\epsilon M}\left\{\sum_{k=1}^{m}\delta(A_i,A_k)\right\}},\ i \in M \tag{17}$$

Step 6: ranking the alternatives according to the values of $\xi(A_i)$; any alternative with a higher value of $\xi(A_i)$ has a higher rank.

Analysis phase. After implementing the TODIM method in Excel software, the results are discussed.

4. Results

BBWM was used to weight the IoT enablers in SSC. For this purpose, first the questionnaire was distributed among the experts. The experts made pairwise comparisons and determined a number between 1 to 9 for each comparison. Table 5 provides the pairwise comparisons of the best criterion to other criteria of SSC. For example, in the opinion of expert #3, the best criterion is the economic criterion (C_1), which is assigned a value of 1. Therefore, he makes Best-to-others pairwise comparisons based on this criterion. Also, according to expert #3, the worst criterion is the social criterion (C_3), which is assigned a value of 5. This value indicates that the priority of the economic criterion (C_1) over this criterion (C_3) is equal to 5. So, the expert makes Others-to-worst pairewise comparisons based on this criterion. All other pairwise comparisons are made in a similar way. The final weights of the sustainability dimensions, including economic, environmental, and social aspects, are shown in Table 6.

Table 8
Final weights of the IoT enablers in the economic dimension (C_1) of SSC.

Enablers	Final weights
C_{11}	0.194
C_{12}	0.159
C_{13}	0.129
C_{14}	0.096
C_{15}	0.171
C_{16}	0.073
C_{17}	0.073
C_{18}	0.113

After calculating the final weights of the SSC dimensions, the confidence levels of the ranking of the dimensions are calculated (Fig. 2). As shown in Fig. 2, the economic criterion (C_1) is at the highest point. Each number inserted on a directional line between two criteria indicates the confidence level of the superiority of source criterion over destination criterion. For example, the confidence level of the superiority of the economic criterion (C_1) over the social criterion (C_2) is equal to 96 %,

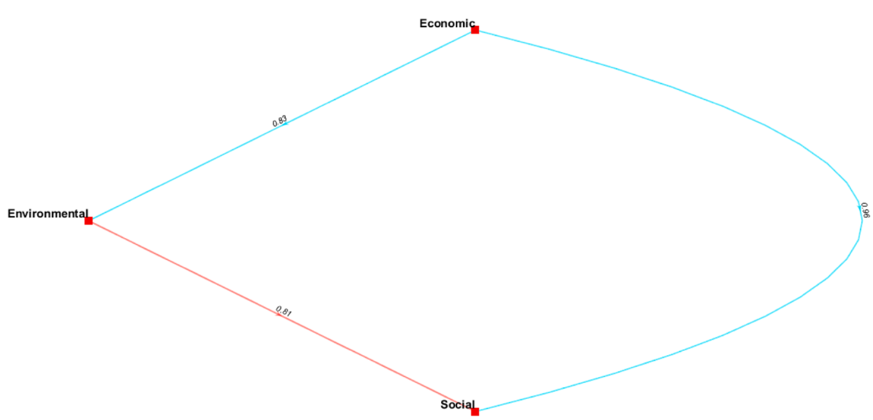

Fig. 2. The confidence levels of the superiority of the SSC dimensions over each other.

Table 7
Best-to-others and Others-to-worst expert-made pairwise comparisons for the IoT enablers in the economic dimension (C_1) of SSC.

Expert	Best enabler	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	Expert	Worst enabler	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}
1	C_{11}	1	3	3	5	2	4	6	2	1	C_{17}	6	4	3	3	5	3	1	2
2	C_{15}	2	2	2	4	1	6	5	4	2	C_{16}	5	4	2	2	6	1	3	4
3	C_{12}	2	1	2	2	2	5	7	3	3	C_{17}	6	7	5	4	5	5	1	4
4	C_{11}	1	2	2	5	2	3	4	2	4	C_{14}	5	3	2	1	2	4	3	2
5	C_{17}	2	3	3	3	2	6	1	2	5	C_{16}	5	5	3	2	4	1	6	3
6	C_{15}	2	3	3	2	1	5	7	3	6	C_{17}	6	6	4	3	7	5	1	5
7	C_{11}	1	2	2	3	2	8	5	3	7	C_{16}	8	7	5	5	7	1	3	2

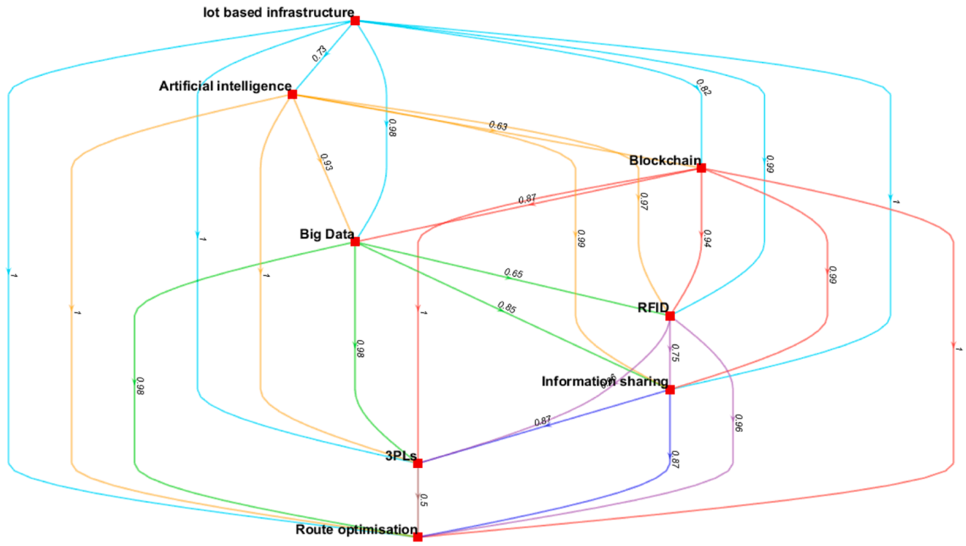

Fig. 3. The confidence levels of the IoT enablers in the economic dimension (C_1) of SSC.

Table 9
Best-to-others and Others-to-worst expert-made pairwise comparisons for the IoT enablers in the environmental dimension (C_2) of SSC.

Expert	Best enabler	C_{21}	C_{22}	C_{23}	Expert	Worst enabler	C_{21}	C_{22}	C_{23}
1	C_{23}	5	2	1	1	C_{21}	1	4	5
2	C_{23}	3	2	1	2	C_{21}	1	2	3
3	C_{23}	2	4	1	3	C_{22}	1	4	2
4	C_{22}	2	1	3	4	C_{23}	2	3	1
5	C_{23}	2	3	1	5	C_{22}	2	1	3
6	C_{22}	3	1	2	6	C_{21}	1	3	2
7	C_{22}	3	1	4	7	C_{23}	3	4	1

Table 10
Final weights of the IoT enablers in the environmental dimension (C_2) of SSC.

Enablers	Final weights
C_{21}	0.247
C_{22}	0.395
C_{23}	0.358

which indicates that 96 % of the experts agree on the superiority of the economic criterion (C_1) over the social criterion (C_2).

After calculating the confidence levels of the SSC dimensions, the weights of the enablers of IoT in the economic dimension of SSC are calculated. Tables 7 and 8 provide pairwise comparisons and final weights of IoT enablers in the economic dimension of the SSC, respectively. The related confidence levels are shown in Fig. 3.

Then, the weights of the IoT enablers in the environmental dimension of SSC are calculated. Tables 9 and 10 provide pairwise comparisons and final weights of the IoT enablers in the environmental dimension of SSC, respectively, and Fig. 4 shows the related confidence levels.

Also, the weights of the IoT enablers in the social dimension of SSC are calculated. Pairwise comparisons and final weights of the IoT enablers in the social dimension of SSC are provided in Tables 11 and 12, respectively, and the related confidence levels are shown in Fig. 5.

Finally, the final weight of each IoT enabler is obtained by multiplying the weight of that enabler by the weight of the corresponding SSC dimension (Table 13). As can be seen in Table 13, the waste management with a weight of 0.129 is the most important enabler and the route optimization with a weight of 0.032 is the least important enabler.

We use TODIM technique to rank the supply chains of dairy industries. Mihan, Haraz, Kale and Alis dairy industries are selected for investigation. The relevant data were collected according to the col-

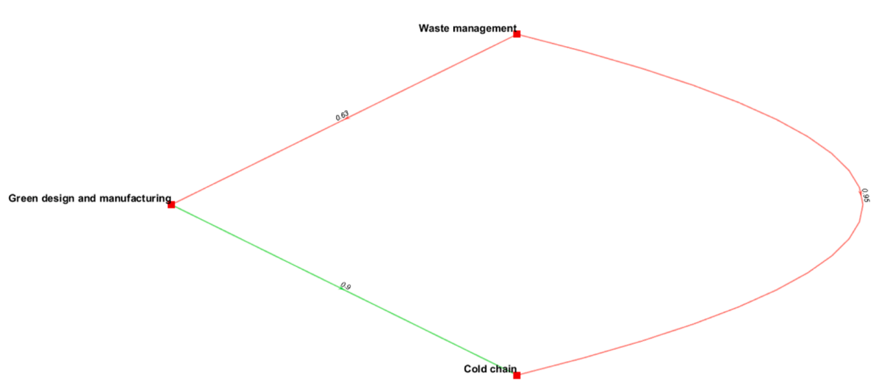

Fig. 4. The confidence levels of the IoT enablers in the environmental dimension (C_2) of SSC.

Table 11
Best-to-others and Others-to-worst expert-made pairwise comparisons for the IoT enablers in the social dimension (C_3) of SSC.

Expert	Best enabler	C_{31}	C_{32}	C_{33}	C_{34}	Expert	Worst enabler	C_{31}	C_{32}	C_{33}	C_{34}
1	C_{32}	6	1	2	4	1	C_{31}	1	6	5	3
2	C_{32}	3	1	2	4	2	C_{34}	3	4	3	1
3	C_{33}	4	3	1	3	3	C_{31}	1	3	4	2
4	C_{33}	5	2	1	3	4	C_{32}	3	1	5	4
5	C_{32}	5	1	2	4	5	C_{31}	1	5	3	3
6	C_{34}	2	2	4	1	6	C_{33}	2	3	1	4
7	C_{34}	4	2	2	1	7	C_{31}	1	3	3	4

Table 12
Final weights of the IoT enablers in the social dimension (C_3) of SSC.

Enablers	Final weights
C_{31}	0.152
C_{32}	0.318
C_{33}	0.293
C_{34}	0.236

lective opinion of the experts; in a face-to-face meeting after explaining the issue, they were asked to complete a questionnaire related to the scores of the IoT enablers in SSC. After collecting the questionnaires, the data were normalized (Table 14). The following relationship was used to normalize the data [40]:

$$Y_{ik}^{j} = \frac{G_{ik}^{j} - G_{j}^{min}}{G_{j}^{max} - G_{j}^{min}},\ i,k\ \epsilon\ M,\ j\ \epsilon\ N,$$

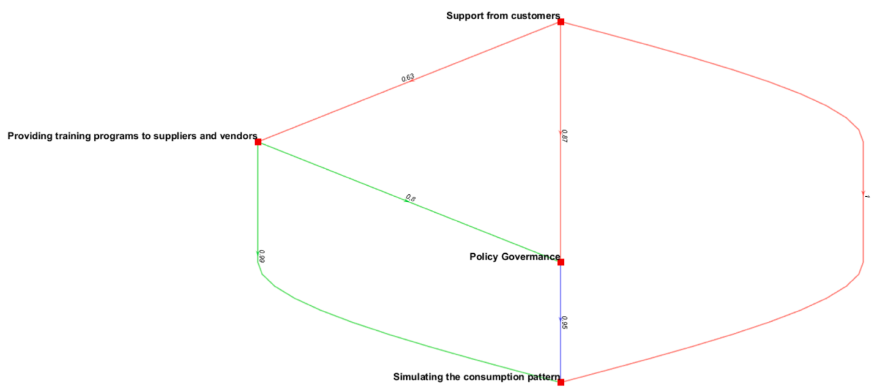

Fig. 5. The confidence levels of the IoT enablers in the social dimension (C_3) of SSC.

Table 13
The final weights of the enablers of IoT in SSC.

Dimensions of SSC	Dimensions weight	IoT enablers in SSC	Local weights of enablers	Global weights of enablers	Final Rank
Economic (C_1)	0.43	Creating the IoTs infrastructure (C_{11})	0.194	0.084	3
		Blockchain (C_{12})	0.159	0.069	8
		Big data (C_{13})	0.129	0.059	10
		Information sharing (C_{14})	0.096	0.042	12
		Artificial inteligence (C_{15})	0.171	0.074	6
		Third-party logistics provider (C_{16})	0.073	0.032	14
		Route optimization (C_{17})	0.073	0.032	15
		RFID (C_{18})	0.113	0.049	11
Environmental (C_2)	0.24	Cold chain (C_{21})	0.247	0.081	4
		Waste management (C_{22})	0.395	0.129	1
		Green design and green production (C_{23})	0.358	0.117	2
Social (C_3)	0.33	Simulation of consumption pattern (C_{31})	0.152	0.038	13
		Consumer protection (C_{32})	0.318	0.079	5
		Providing training programs to suppliers and vendors (C_{33})	0.293	0.073	7
		Government policies (C_{34})	0.236	0.06	9

Table 14
Normalized matrix.

C A	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{34}
A_1	0.57	0	0.29	0	0	0.75	0.04	0	0	0	0	0	0.50	0	0
A_2	0.73	0.54	1	0.44	0/28	1	0	0.09	0.84	0.36	0.39	0.24	1	0.21	0.71
A_3	0	0.92	0	0/72	1	0	1	1	1	0.45	1	0.41	0	0.41	0.83
A_4	1	1	0.29	1	0.58	0.45	0.31	0.33	0.88	1	0.90	1	0	1	1
W_j	0.083	0.068	0.053	0.041	0.073	0.031	0.031	0.048	0.080	0.128	0.116	0.038	0.078	0.072	0.058

Table 15
The degree of dominance of each alternative.

Dominance degree of A_1	Dominance degree of A_2	Dominance degree of A_3	Dominance degree of A_4
$\delta(A_1.A_k)$	$\delta(A_2.A_k)$	$\delta(A_3.A_k)$	$\delta(A_4.A_k)$
-11/929	0/238	-3/613	-1/184
-13/522	-9/422	-5/303	-3/431
-14/270	-10/439	-8/104	-4/126

Table 16
Final ranks of the alternatives.

Alternative	$\sum \delta(A_i.A_j)$	$\xi(A_i)$	Ranking
Mihan (A_1)	-39.720	0	4
Haraz (A_2)	-19.624	0.649	3
Kalleh (A_3)	-17.019	0.733	2
Alis (A_4)	-8.7406	1	1
$A_4 \geq A_3 \geq A_2 \geq A_1$			

$$Z^j_{ik} = \frac{L^j_{ik} - L^{min}_j}{L^{max}_j - L^{min}_j},\ i,k\ \epsilon\ M,\ j\ \epsilon\ N,$$

Where $G^{max}_j = max\left\{G^j_{ik}\middle|i, k\epsilon M\right\}$, $G^{min}_j = min\left\{G^j_{ik}\middle|i, k\epsilon M\right\}$, $L^{max}_j = max\left\{L^j_{ik}\middle|i, \ k\epsilon M\right\}$ and $L^{min}_j = min\left\{L^j_{ik}\middle|i, \ k\epsilon M\right\}$, $j\epsilon N$. Here, $Y^j_{ik}\epsilon[0, 1]$ and $Z^j_{ik}\epsilon[-1, 0]$.

Then, according to the method described in the previous section, the degree of dominance of the alternative A_i over A_k was determined for each C_j indicator using the relation $\delta(A_i.A_k) = \sum_{j=1}^{n} \Phi_j(A_i.A_k)$. The results are provided in Table 15.

Then, the total degree of dominance of each alternative over other alternatives is calculated and the rank of each supplier is obtained based on the maximum value of the calculated $\xi\ (A_i)$. The results are provided in Table 16.

5. Discussion and conclusions

Today, the concept of SSC, as a novel and influential idea, has captured the attention of researchers in the field of supply chain management. Additionally, various factors such as customer satisfaction, flexibility, quality, and more, drive organizations to adopt sustainable supply chain management, particularly in the upstream segments of the supply chain. Employing an SSC is crucial for maintaining the organization's competitive edge in terms of price, quality, reliability, flexibility, and responsibility. Emerging technologies such as IoT can be used to achieve the goals of an SSC. IoT has shown its capabilities in supply chain processes. Utilizing IoT for management, forecasting, and monitoring aids managers in enhancing the operational efficiency of their organizations and enhances the transparency of their decision-making processes. Facilitating tracking and monitoring is another benefit of IoT in SSC. Hence, the aim of this study was to identify the enablers of IoT in SSC.

Sustainability is a concept that tries to consider the economic, social and environmental dimensions of organizations' activities at the same time so that, beside the economic profits that the organization obtains, the consumers are satisfied and the environment is not harmed. Organizations usually focus more on economic profit and do not consider the social and environmental dimensions of their activities. Therefore, it is necessary for organizations to consider environmental and social dimensions in their strategies in order to achieve the goals of sustainable development [55]. The goals of sustainable development in economic, social and environmental dimensions have been determined by the United Nations. The goals of sustainable development in the economic dimension include responsible consumption, use of clean energy, creation of good jobs and creation of innovative infrastructure along with economic growth. Also, health development, poverty eradication, quality education and participation are among the goals of sustainable development in the social dimension. Finally, in the environmental dimension, protecting the environment and the planet are among the goals of sustainable development [137].

According to the literature, IoT also pursues the goals of sustainable development in SSC. Cheng et al. [33] designed a system based on IoT that is able to predict consumption and can enable responsible consumption. Moemen et al. [84] suggested that IoT can enable the use of clean energy. IoT has been considered as a main enabler of economic growth in China [56] and Indonesia [126]. IoT can play important roles in the fields of health [106], quality education [60] and poverty alleviation [92]. The enablers of IoT in SSC, which were identified in the current study, also follow the goals of sustainable development. Blockchain plays roles in responsible consumption [112], the use of clean energy [111], good jobs and economic growth [48], health [54], poverty eradication [95], quality education [30] and the planet protection [37]. Fig. 6 shows the relationships between the sustainable.

5.1. Theoretical Implications

In this study, the enablers of IoT in SSC were evaluated. SSC, as a novel and highly influential concept, has garnered the interest of researchers in the field of supply chain management. According to the literature, emerging technologies such as IoT play an important role in SSC. Also, the goals of IoT in SSC are in line with the SDGs. Despite the important role that IoT can play in SSC, little research has been conducted regarding the identification of the IoT enablers in SSC. Identifying the enablers of IoT in the sustainability of the food supply chain can help prevent food wastage and also provide value to customers and stakeholders. Therefore, the current study focused on identifying and evaluating the enablers of IoT in SSC. The results of this study showed that waste management is very important. Wastes are valuable resources that its proper management can have many positive effects on the economy, society and environment [35], can help achieve sustainability in economic, social and environmental fields [90], and can also optimize the SSC [85]. Another use of waste is medical waste, which is very important to manage [39]. C. Wang et al. [123] stated that in modern cities, waste management is a necessary part that improves the lives of residents and prevents the wastage of resources. Bisinella et al. [23] stated that waste management plays an important role in life cycle assessment. Also, waste management follows all the goals of sustainable development [17,36,43,47,70,83,101,104,114,117]. IoT can improve the effectiveness of waste management by creating innovative solutions and enable the beneficial use of waste [110,125].

5.2. Practical implications

This study provides deep insight for supply chain managers about IoT enablers to achieve sustainable goals in three cases. First, according to the findings, waste management is one of the important enablers in the sustainability of the supply chain based on IoT. The experts of this study acknowledged that waste management increases the efficiency of environmental and economic aspects. Since there is waste in the food industry during production and after production, supply chain managers can manage waste and increase productivity in the organization by using the IoT. According to the interviews with the experts, using waste and returning it to the supply chain can have a significant impact on the profitability of the food industry. Also, paying attention to enablers such as waste management, design, and green production increases customer satisfaction.

Second, the implementation of IoT enablers will make supply chain processes faster and provide managers with accurate analytics [15]. In this way, organizations can achieve sustainability and reduce risks in the supply chain. However, implementing incentives takes time. Therefore, it is recommended that organizations establish a flexible structure in the

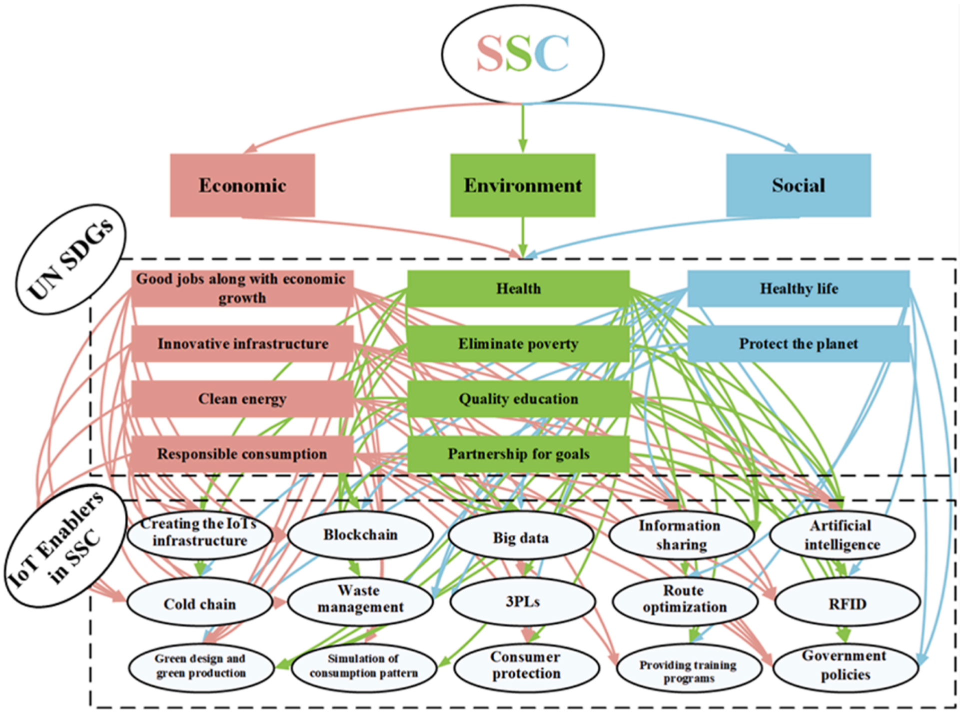

Fig. 6. Relationships between the SDGs and the IoT enablers in SSC.

organization to supervise the implementation of incentives and ensure the implementation of strategies for the implementation of incentives in the supply chain.

Last but not least, while the IoT with its capabilities can attract the trust of stakeholders in strategic organizational decisions and increase investments [75], there are obstacles such as employee resistance that prevent the full implementation of enablers in the supply chain [32]. Hence, managers can familiarize employees with the goals and applications of the IoT by holding training courses. By doing so, the implementation of the IoT enablers in the supply chain will enjoy a favorable speed and sustainable goals will be achieved in the supply chain. In addition, the implementation of stimuli causes changes in organizational processes. Accordingly, it is essential that supply chain managers promote a culture of changeability in organizations in order to increase the productivity and effectiveness of the IoT in the supply chain.

5.3. Limitations and Future research directions

In this study, combining qualitative and quantitative approaches, the enablers of IoT in SSC were identified and analyzed. However, this study has limitations that highlight promising directions for future research. From the perspective of the research scope, all experts in this study were active in the emerging economy of Iran and had limited experience in implementing IoT in SSC. Hence, the results of this study are limited to developing countries. Therefore, it is suggested that future research examines the objectives and questions of this study in developed countries and compares the results with this study. Also, the primary data is based on the experience and intuition of the experts in this study. Although the experts were selected from specific filters, their experience was limited. Hereupon, it is recommended that future researchers collect and analyze primary data to assess the enablers of IoT on supply chain sustainability through empirical research. In addition, secondary data was collected through library studies. However, there were limitations in data collection. Therefore, future researchers can identify the enablers of IoT in SSC through structured and semi-structured interviews and compare the results with this study.

The research context in this study is based on the impact of technological resources on SSC. Thus, the impact of resources such as physical, human, financial, etc. on SSC has been ignored. Therefore, researchers in the future can consider other resources such as human resources, and examine their impact and challenges on SSC. This will provide new solutions in this area and increase the attractiveness of the subject. In addition, considering the methodological aspect, this paper has analyzed the enablers of the IoT in SSC through the combination of BBWM-TODIM. However, the cause-and-effect enablers were not identified in BBWM-TODIM. Identifying the cause-and-effect enablers can lead to a more accurate understanding of them and adopt appropriate strategies to increase their effectiveness and efficiency. Hence, it is recommended that researchers use the DEMATEL to identify the cause and effect variables. Furthermore, future researchers can use Interpretive structural modeling (ISM), which indicates the type of criteria (linkage, independent, autonomous, dependent), to add new insights in this area.

CRediT authorship contribution statement

Hojatallah Sharifpour Arabi: Methodology, Investigation, Formal analysis, Writing – original draft, Conceptualization. **Hamidreza Fallah Lajimi:** Writing – review & editing, Formal analysis, Supervision, Data curation, Software. **Maghsoud Amiri:** Validation, Supervision, Writing – review & editing, Formal analysis. **Mohammad Hashemi-Tabatabaei:** Formal analysis, Writing – review & editing, Supervision, Data curation, Investigation, Validation. **Seyed Khadije Hosseini:** Investigation, Writing – original draft, Visualization.

Declaration of competing interest

There are no conflicts of interest regarding the article.

Data availability

Data will be made available on request.

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