International Journal of Applied Operational Research
Vol. 12, No. 4, pp. 69-84, Autumn 2024

Journal homepage: ijorlu.liau.ac.ir

Identify and prioritize industry 4.0 technology in supply chain finance based on sustainability approach

Z. Zamami, M. Moradi *, M. Ebrahimpour

Received: 14 May 2024; **Accepted:** 22 August 2024

Abstract This study seeks to systematically identify and prioritize the Industry 4.0 technologies that influence sustainable supply chain finance and assess the individual impacts of these technologies on the sustainability of supply chains. Industry 4.0 represents a transformative paradigm shift in manufacturing and service sectors, characterized by the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), cloud computing, robotics, and other cutting-edge innovations into production and service operations. These technological advancements are associated with significant improvements in productivity, cost efficiency, product and service quality, speed of production and delivery, and worker safety, among other outcomes. In parallel, sustainable supply chain finance refers to the strategic deployment of financial resources aimed at supporting supply chains that adhere to economic, social, and environmental sustainability principles. By ensuring that both companies and their suppliers comply with sustainability standards, this approach plays a pivotal role in strengthening and maintaining a resilient and responsible supply chain, thereby delivering substantial benefits to society and the environment. As global supply chains become increasingly interconnected and complex, the ability to integrate Industry 4.0 technologies within the framework of sustainable finance has the potential to reshape not only operational efficiencies but also contribute to long-term societal welfare and environmental stewardship. This research provides valuable insights into how these technological innovations can drive sustainability within financial structures, offering a pathway for future-proofing supply chains in the face of emerging global challenges. This study is both applied and expert-oriented, focusing on the sub-criteria within the economic, social, and environmental dimensions of sustainable supply chain finance, in the context of emerging Industry 4.0 technologies.

Keyword: Sustainable supply chain finance, Industry 4.0, Sustainability, Supply chain finance.

1 Introduction

Sustainable supply chain finance refers to methods in which supply chain finance is implemented in a way that trade and transactions are carried out sustainably. The goal of these methods is to promote economic, environmental, and social issues, while also helping to

* **Corresponding Author. (✉)**
E-mail: m.moradi@guilan.ac.ir (M. Moradi)

Z. Zamami
Faculty of Management and Economics, University of Guilan, Rasht, Iran

M. Moradi
Department of Management, Faculty of Management and Economics, University of Guilan, Rasht, Iran

M. Ebrahimpour
Department of Management, Faculty of Management and Economics, University of Guilan, Rasht, Iran

[DOI: 10.71885/ijorlu-2024-1-680]

reduce any negative impacts on all stakeholders involved in delivering goods and services to the market [1]. The term "sustainable supply chain finance" was first introduced by a U.S. organization in 2018.

With industrialization, sustainability has emerged as a critical issue in the global market, drawing the attention of managers and organizations. Ignoring sustainability issues can lead to financial losses and damage to reputation in the market. However, the adoption of sustainability in developing economies is lower [2].

Implementing sustainable supply chain finance can lead to the creation of a sustainable supply chain and an enhanced image for the company, thus gaining a competitive advantage [3]. In addition to positive environmental outcomes, sustainable supply chain finance can also contribute to social sustainability. As suppliers in underdeveloped regions benefit from supply chain finance programs, they gain more opportunities to access financial and economic resources [4].

The concept of Industry 4.0 refers to a new digital industrial revolution that enables the integration of organizational capabilities with sustainable technologies. This integration creates an agile, flexible, and efficient environment for industries [5]. The application of Industry 4.0 technologies can enhance the implementation of sustainable supply chain finance through automation and streamlining of supply chain finance processes, thereby assisting companies within the supply chain [6,7].

For small and medium-sized enterprises (SMEs) facing financial constraints, optimizing financial flows in the supply chain can improve their performance and investment potential. By leveraging Industry 4.0 technologies, which have high potential for improving industrial supply chain efficiency, these companies can enhance their working capital and competitiveness, while also improving their performance in sustainable supply chain finance [1].

Industry 4.0 reduces operational costs, improves quality, increases productivity, and fosters innovation. However, the adoption of Industry 4.0 technologies in SMEs is limited due to financial constraints. If a company wants to implement Industry 4.0 technologies related to sustainable supply chain finance, it may not be able to implement all options due to limited capital and associated risks. This research, considering all aspects and requirements of the company, proposes the best technology related to sustainable supply chain finance for SMEs. The purpose of this study is to identify the most important dimensions of sustainable supply chain finance and prioritize the Industry 4.0 technologies related to it.

The importance and necessity of this research is significant as it explores the integration of Industry 4.0 technologies with sustainable supply chain finance. Given the global economic and environmental challenges, sustainability in supply chains has become a critical priority for companies. The adoption of Industry 4.0 technologies can help improve efficiency, reduce costs, and enhance quality within supply chains, enabling companies to adopt more sustainable practices. This study is particularly important for small and medium-sized enterprises (SMEs) that face financial constraints, as it offers solutions based on advanced technologies to help them improve their performance in sustainability while gaining a competitive edge. Ultimately, this research can contribute to the development of innovative financing models and the improvement of economic and social infrastructures, particularly in developing regions.

2 Literature review

2.1 The Concept of Sustainability

Sustainability is highly significant in today's world, and many companies are currently trying to implement sustainable practices in their operations. These actions are intended to create a positive image of their brand. Sustainability is based on three pillars: social, environmental, and economic elements.[8]

2.1.1 Environmental Sustainability

The environment is currently facing many challenges. The increasing population and human activities have had significant impacts on natural resources. Air, water, and soil pollution, biodiversity loss, and deforestation are among the issues that need attention. To preserve the environment and natural resources, it is necessary to use resources sustainably and promote environmentally friendly practices. Most importantly, international cooperation is crucial to solving environmental problems [9].

2.1.2 Economic Sustainability

An economy that focuses on providing good living standards, necessary services for people, and creating job opportunities should be designed with sustainability and long-term economic development in mind. This is very important because sustainable societies require a balance between economic growth and the preservation of resources and the environment. Increasing GDP (national production) without considering harmful effects can lead to problems such as environmental pollution, social inequality, and depletion of natural resources. Therefore, the economy must focus on meeting the current needs of humanity while preserving resources for future generations [10].

2.1.3 Social Sustainability

The emphasis on social sustainability is one of the key concepts in sustainability. This concept includes various factors such as health, justice, cultural development, and other social aspects that directly impact individuals' quality of life. Since a precise definition of social sustainability and effective actions to support it have not yet reached global consensus, discussions on this topic continue. For example, this may lead to an improvement in the quality of life for individuals, even if it results in a decrease in per capita GDP. This concept is more about the balance between material consumption and resources in relation to needs, cultural and social development, and ensuring reasonable and fair living conditions, which may temporarily change. This definition aims to help improve the quality of life [10].

2.2 Sustainable Supply Chain Finance

Since the 1970s, with the growing market demand for various products, many organizations have turned to risky yet cost-saving production methods; however, these actions jeopardized the long-term effects on society and the environment. Industrial accidents, including the Amoco Cadiz oil spill in France, the Bhopal gas disaster in India, the Chernobyl nuclear

[DOI: 10.71885/ijorlu-2024-1-680]

accident in Ukraine, and the Exxon Valdez oil spill in the United States, highlighted the urgent need to reassess business models and evaluate the economic consequences for society and the environment. These incidents prompted regulatory authorities, producers, customers, and society to reconsider economic business models, enhance safety standards, and protect the environment [11].

Sustainable supply chain finance, as an operational framework, emphasizes that it not only affects the logistics, information flow, and capital flow of each company within the supply chain but also influences the performance of other companies through positive externalities in the economy, environment, and society. This framework creates environmental, social, and economic benefits in a way that minimizes negative impacts for all stakeholders [12]

The integration of SSCF represents a fundamental shift in how businesses approach financing, supply chain management, and sustainability. By leveraging finance for positive impact, businesses not only enhance their financial performance and mitigate risks but also generate significant environmental and social benefits that support both current and future generations. As we move forward on this journey toward greater sustainability, it's essential to stay committed to collaboration, innovation, and shared responsibility. Sustainable supply chain financing is not merely a business necessity, but a moral obligation to create a better world [7].

Table 1. Sustainable supply chain finance (SSCF) criteria.

Aspect	Criteria
Economic	Trade credit
	Cash management
	Inventory control
	Raw material procurement
	Service delivery management policies
Social	Stakeholder engagement
	Stakeholder empowerment
	Stakeholder and customer satisfaction
	Stakeholder regulations
	Buyer-supplier partnership
Environment	Environmental policy
	Reduce, reuse, and recycle of energy and wastewater
	Environmental costs
	Green technology

2.3 Industry 4.0

The First Industrial Revolution occurred in the mid-18th century, initially in England and later spread throughout Europe and the world, fueled by the invention of the steam engine. In the second half of the 19th century, the Second Industrial Revolution took place, marked by mass production and the use of chemical and electrical energy. During this revolution, several

[DOI: 10.71885/ijorlu-2024-1-680]

industrial technologies and mechanization methods were invented to increase production and demand, including assembly lines with automated operations that helped boost productivity. The invention of the integrated circuit (microchip) was a technological advancement that led to the Third Industrial Revolution. The use of electronics and information technology to achieve greater automation in production was the key feature of this revolution, which emerged in many industrialized countries by the late 20th century [13]

The Fourth Industrial Revolution will lead to full automation and digitalization of processes, as well as the utilization of electronics and information technology in production and service delivery within a private environment [14].

Currently, the Fourth Industrial Revolution, known as Industry 4.0, encompasses rapid and innovative changes that affect the fields of digital manufacturing, network communications, computers, automation technologies, and many other related areas [15].

Table 2. Industry 4.0 related technologies

Dimension	Technologies	Definitions
Information technologies	Cloud computing	The technology that supports the Internet of Things enables access to large datasets and processes them to generate new useful information through various reports [15].
	Data analysis	The era of digital transformation, data analysis has become more crucial than ever. Data analysis helps organizations understand this data and turn it into actionable insights. These insights can be used to improve products and services, enhance experiences, streamline operations, and increase profitability [16].
	big data	Big data is a term for large datasets that are characterized by their vast size, greater diversity, and complexity for analyzing and visualizing processes or future outcomes [17].
	Internet of Things	The Internet of Things (IoT) refers to services and data that enable communication between objects by embedding intelligence into them, transforming them into smart objects. These smart objects are not only capable of collecting information from their environment and interacting with or controlling the physical world, but they can also connect to each other via the internet to exchange data and information [15].
Operational technologies	Autonomous Robots	Automated robots can identify problems and autonomously adjust their tasks to ensure that processes are executed smoothly, and they are used to replicate human actions in production [18].
	operation control and automation	It refers to the process of controlling a system or a process automatically and without the need for human intervention [19].
	Virtual reality	Virtual reality is an advanced human-computer interface that simulates a real environment. Individuals can move within the virtual world. They can view it from different angles, interact with it, and alter its shape [20].
	Augmented Reality	It represents the integration of virtual and real environments, where objects in the real world are enhanced

[DOI: 10.71885/ijorlu-2024-1-680]

		by information or computer-generated objects using various technologies. It can also be combined with human capabilities to provide efficient and complementary tools to assist with production tasks [21].
	digital twin	An emerging and vital technology for digital transformation and smart upgrading. By leveraging data and models, the digital twin can perform monitoring [20].
Customer related technologies	Tracking systems	It is a technology that sends precise signals, allowing the receiver to calculate and display accurate information about location, speed, and time to the user [22].
	Online stores	They sell goods and services online, and the advantages of these types of stores include variety, convenience, and a diverse range of brands [23].
	CRM software	A business strategy that focuses on the customer and helps companies improve and effectively manage relevant information about their customers. Nowadays, companies are paying attention to increasing customer value through the analysis of the customer lifecycle. Tools and technologies, data mining, and other customer relationship management techniques provide new opportunities for businesses to act based on marketing concepts and prioritize customer requests [24].
Financial technologies	Cryptocurrency	A digital peer-to-peer exchange system in which cryptography is used to generate and distribute units of currency [21].
	Blockchain	It is a distributed database that maintains a continuously growing list of records in a fully distributed and tamper-proof manner using new encryption and authentication technologies at the network level [18].
	Electronic wallet	Virtual cash or cashless transactions is a technology that has seen tremendous growth in recent years. Cashless payments have now become a popular trend in almost every sector [25].

2.4 Industry 4.0 and sustainable supply chain finance

Improving the efficiency and performance of small and medium-sized enterprises (SMEs) is crucial due to their central role in strengthening a country's economy. For SMEs, capital constraints act as a barrier to their growth; however, by optimizing financial flows within the supply chain, the performance and investment potential of these companies can be enhanced. Industry 4.0 technologies, including the Internet of Things (IoT), cloud computing, big data, and data analytics, can play a significant role in this regard. By utilizing Industry 4.0 technologies for sustainable supply chain finance, SMEs can increase their working capital and competitiveness [1]. Due to continuous global growth and changes, companies are increasingly considering sustainable mechanisms and innovation as key tools for gaining competitive advantage and economic development. Digital manufacturing systems are among the tools that help companies create more sustainable and economically efficient processes while promoting innovation. These changes not only improve the performance of companies but also create optimal conditions for advancing global economic development goals [25].

[DOI: 10.71885/ijorlu-2024-1-680]

Ernesto Mastrocinque and Colleagues, in a 2022 paper titled "Industry 4.0 enabling sustainable supply chain development in the renewable energy sector: A multi-criteria intelligent approach," [26] conducted a comprehensive study on identifying the key criteria influencing social, economic, and environmental sustainability in the photovoltaic energy supply chain and examined the potential impact of Industry 4.0 on sustainability. Experts' opinions were used to identify the impact of Industry 4.0 technologies on the three pillars of sustainability for each stage of the supply chain. Ultimately, a new sustainability index, the 4.0 Sustainability Index, was formulated to calculate the overall sustainability of the photovoltaic energy supply chain across seven countries. The results demonstrate the application and usefulness of the proposed holistic model in assisting policymakers, stakeholders, and users in making informed decisions for the development of sustainable renewable energy supply chains, considering the impact of Industry 4.0 and digital technologies.

MH Naseem and J Yang, in a 2021 paper titled "Role of industry 4.0 in supply chains sustainability: A systematic literature review," [27] state that Industry 4.0 has a significant impact on the sustainability of supply chain networks and further explain that various Industry 4.0 technologies contribute to the sustainability of supply chains in business. They propose a framework that identifies the impact of Industry 4.0 technologies on the supply chain. The review articles were collected from Google Scholar and ScienceDirect, and this paper also expands the existing knowledge in current fields.

Manavalan and Jayakrishna K., in a 2019 paper titled "A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements" [28] state that supply chain organizations today operate in a dynamic and complex market. Sustainable supply chains are critical to responding to rapid changes and customer needs. The reviews show that manufacturing companies must increase the speed of their transformations and focus on sustainability, using technologies such as the Internet of Things (IoT) to achieve organizational goals. The paper investigates various aspects of supply chain management, enterprise resource management, IoT, and Industry 4.0, and explores the potential opportunities for an IoT-embedded sustainable supply chain in the Industry 4.0 transformation. In this study, various factors affecting sustainable supply chains are analyzed, and a framework is proposed to assess the readiness of supply chain organizations from multiple perspectives to respond to the Fourth Industrial Revolution. This conceptual model framework is formulated from five key perspectives in supply chain management: business, technology, sustainable development, collaboration, and strategy management. This research provides criteria that can be used to assess companies' readiness for Industry 4.0 transformation, which, in turn, can improve performance and sustainability in the supply chain.

3 Methods

The Best-Worst Method (BWM) is a multi-criteria decision-making technique in which pairwise comparisons are made to allocate weights to criteria. The two main models of BWM are the nonlinear MinMax model and the linear model. The linear model, due to its need for unique weights and its ability to minimize discrepancies, has been selected for this study [29,30]. In this research, this method is employed, and the results are ultimately calculated using GAMS software, which is based on the Best-Worst Method.

[DOI: 10.71885/ijorlu-2024-1-680]

The experts in this study consist of 10 individuals, including 2 academic specialists, 1 CEO, 2 experts, and 5 middle managers. Five of the experts hold PhD degrees, while the other five hold Master's degrees. The work experience of 4 individuals ranges from 11 to 15 years, and 6 individuals have more than 15 years of experience. In order to identify certain factors, related literature have been used. Initially, a questionnaire was conducted with the experts, and the factors were determined. Then, the BWM method was applied to evaluate and prioritize the indicators. After the analysis, the BWM questionnaire was used.

In the Best-Worst Method, two questionnaires were developed: one focusing on Industry 4.0 and the other on sustainable supply chain finance. The first questionnaire contained 5 questions, and the second also included 5 questions. Each question had three parts. In the first part, the experts were asked to select the best (most important) and worst (least important) criteria. In the second part, the experts were asked to perform a relative preference comparison between the best criterion and the other criteria on a scale of 1 to 9. In the third part, they were asked to perform a relative preference comparison between the other criteria and the worst criterion on the same 1 to 9 scale.

BWM (Best Worst Method) consists of five main steps:

Step 1: Defining a Set of Criteria:

In this step, a set of criteria $\{C_1, C_2, \ldots, C_n\}$ is defined, which will be used by the decision-maker to make decisions regarding the best option. For example, when choosing a house from several options, a set of criteria may include {location (C_1), price (C_2), size (C_3), style (C_4)}.

Step 2: Identifying the Best (Most Important or Desired) and Worst (Least Important or Undesirable) Criteria:

In this step, the decision-maker must identify the best and worst criteria in general terms. Comparisons between criteria have not yet been made at this stage. For example, a decision-maker might choose location (C_1) as the best criterion and style (C_4) as the worst criterion when buying a house.

Step 3: Determining Preferences of the Best Criterion Over Other Criteria:

The decision-maker should determine the preferences of the criteria in relation to the best criterion. A selection of 1 means that the criterion in question is equally important as the most important criterion, while a selection of 9 indicates that the most important criterion is much more significant and valuable than the criterion in question, which holds relatively little value. This results in the vector AB (pairwise comparisons of the best criterion relative to the others).

$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$

In this vector, $a_{BB} = 1$, since this value represents the preference of the best criterion relative to itself. The previous example includes the priority of location (C_1) over the other four criteria.

Step 4: Determining Preferences of Criteria Over the Worst Option:

The decision-maker should determine the preferences of all criteria relative to the worst criterion using a scale from 1 to 9. A selection of 1 indicates equal importance, and a selection of 9 indicates that the respective criterion is much more important than the worst criterion, which is of minimal importance. This results in the vector AW (pairwise comparisons of criteria relative to the worst criterion).

$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})$

[DOI: 10.71885/ijorlu-2024-1-680]

In this vector, $a_{WW} = 1$, since this value represents the preference of the worst criterion relative to itself. The previous example includes the preferences of all criteria relative to style.

Step 5: Finding the Optimal Weights:

In this step, the optimal weights $(W_1^*, W_2^*, \dots, W_n^*)$are determined. As previously mentioned, two different models for BWM are proposed: first, it can lead to multiple optimal solutions, and second, the goal is to find unique weights. The linear model for this research uses unique weights. A set of optimal weights for the linear model is where the maximum absolute difference for the set $\{|W_B - a_{Bj}W_j|, |W_j - a_{jw}W_w|\}$is minimized. The sum of the weights is equal to one, and none of the weights can be negative, resulting in the following equation to find the optimal solution.

$$Min\, max\{|W_B - a_{Bj}W_j|, |W_j - a_{jw}W_w|\}$$

$$s.t. \quad \sum_j^{s.t} W_j = 1$$

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

This problem can be solved by transforming it into a linear programming problem with the following equation.

$$Min\ \ \xi^L$$

$$s.t.\ |W_B - a_{Bj}W_j| \leq \ \xi^L, for\ all\ j$$

$$|W_j - a_{jw}W_w| \leq \ \xi^L, for\ all\ j$$

$$\sum_j Wj = 1$$

Solving this linear programming problem results in a unique solution where the optimal weights are $(W_1^*, W_2^*, \dots, W_n^*)$and ξ^Lrepresents one of the comparisons made in this model. The value of ξ^Lindicates the reliability of the results based on how well the comparisons align. A value close to zero indicates a high consistency and reliability. Complete consistency is achieved when:

$a_{Bj} * a_{jW} = a_{BW}$for all j.

Calculation of the consistency rate

Using the obtained $\xi^L$the consistency rate is calculated. It is evident that a larger ξ^Lvalue indicates a higher consistency rate. Since $a_{BW} \in \{١,٢,\dots,٩\}$ and $a_{Bj} * a_{jW} = a_{BW}$ the maximum value of ξ^Lcan be determined.

3.1 Analysis of Criteria

After the conducted analyses, 4 main criteria and 15 sub-criteria were identified for Industry 4.0, and 3 main criteria and 14 sub-criteria were identified for sustainable supply chain finance (Table 3 and Table 4).

[DOI: 10.71885/ijorlu-2024-1-680]

Table 3. I4.0 related criteria and sub-criteria

Aspect	Criteria
Financial technologies	Cryptocurrency
	Blockchain
	Electronic wallet
Customer related technologies	Tracking systems
	Online stores
	CRM software
Operational technologies	Autonomous Robots
	Operation control and automation
	Virtual reality
	Augmented Reality
	digital twin
Information technologies	Cloud computing
	Data analysis
	big data
	Internet of Things

Table 4. Sustainable supply chain financing related criteria and sub-criteria

Aspect	Criteria
Economic	Trade credit
	Cash management
	Inventory control
	Raw material procurement
	Service delivery management policies
Social	Stakeholder engagement
	Stakeholder empowerment
	Stakeholder and customer satisfaction
	Stakeholder regulations
	Buyer-supplier partnership
Environment	Environmental policy
	Reduce, reuse, and recycle of energy and wastewater
	Environmental costs
	Green technology

3.2 Findings from Industry 4.0 Analysis

All the criteria and sub criteria for Industry 4.0 were examined and weighted using the BWM method. criteria include Financial technologies, Customer related technologies, Information

[DOI: 10.71885/ijorlu-2024-1-680]

technologies and Operational technologies. sub criteria of Financial technologies include Cryptocurrency, Blockchain, Electronic wallet and sub criteria of Customer related technologies include Tracking systems Online stores, CRM software and sub criteria of Operational technologies include Autonomous Robots Operation control and automation, Virtual reality, Augmented Reality, digital twin and sub criteria of Information technologies include Cloud computing Data analysis big data Internet of Things.

The final rankings of these criteria are presented in Table [5]. Based on the obtained weights, Operation control and automation (0.1288), Internet of Things (IoT) (0.1201), and Data Analytics (0.1190) ranked first to third, respectively. The comparison between them is shown in Figure [1].

Table 5. I4.0 criteria ranking

Dimensions	Weights	Sub-criteria	Weight	Global weight	Global rank
Information technologies	0.4005	Cloud computing	0.2089	0.083	5
		Data analysis	0.2970	0.1190	3
		Internet of Things	0.2999	0.1201	2
		big data	0.1939	0.0777	6
Operational technologies	0.2994	Autonomous Robots	0.1822	0.0545	8
		Operation control and automation	0.4301	0.1288	1
		Virtual reality	0.1447	0.0433	10
		Augmented Reality	0.1210	0.362	14
		digital twin	0.1217	0.00364	13
Customer related technologies	0.1576	Tracking systems	0.1734	0.0273	15
		Online stores	0.2679	0.0422	11
		CRM Software	0.5585	0.0880	4
Financial technologies	0.1423	Cryptocurrency	0.2601	0.0730	12
		Blockchain	0.4257	0.0605	7
		Electronic wallet	0.3141	0.0447	9

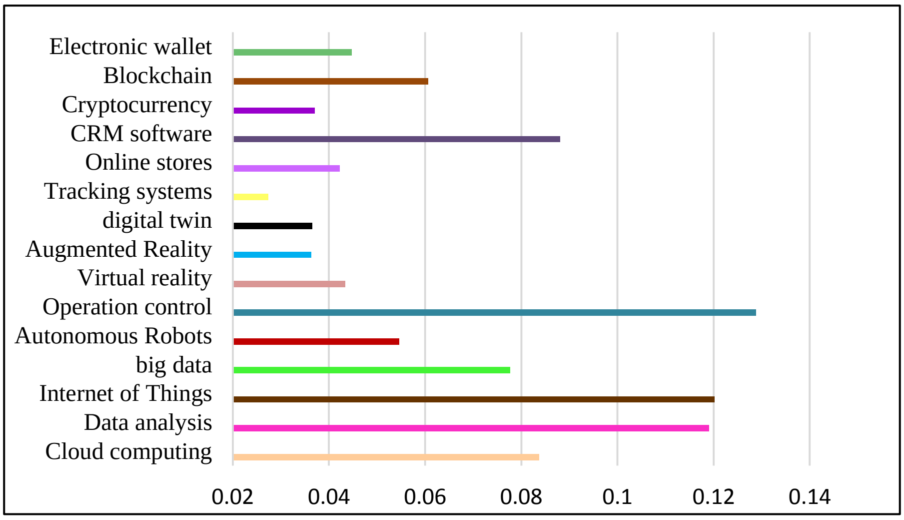

Fig.1 Criteria and sub criteria ranking related to I4.0

[DOI: 10.71885/ijorlu-2024-1-680]

In this stage, the main criteria were compared using the GAMS software, and based on the results, Information technologies, Operational technologies, and Customer related technologies ranked first to third, respectively. In the next stage, all the sub-criteria were compared, and based on the results, Operation control and automation, Internet of Things, and Data analysis achieved ranks one to three, respectively. Based on the results, with Operation control and automation ranking first, it can be concluded that reducing human errors, increasing productivity, and responding better to changes and innovations are of high importance for the company. To achieve these goals, they can use automatic control and process automation.

3.3 Findings from Sustainable Supply Chain Finance

All the criteria and sub-criteria of sustainable supply chain finance were examined and weighted using the BWM method. criteria include Economic, Social and Environment. Sub criteria of Economic include Trade credit, Cash management, Inventory control Raw material procurement and Service delivery management policies. sub criteria of Social include Stakeholder engagement, Stakeholder empowerment, Stakeholder and customer satisfaction, Stakeholder regulations and Buyer-supplier partnership and sub criteria of Environment include Environmental policy, Reduce, reuse, and recycle of energy and wastewater, Environmental costs and Green technology.

All of these criteria were ranked in the final ranking, as shown in Table ٦. Based on the obtained weights, Trade credit (0.1335), Stakeholder engagement (0.1180), and Stakeholder and customer satisfaction (0.1178) were ranked first to third, respectively, and the comparison between them is shown in Figure 2.

Table 6. Sustainable supply chain financing and I4.0 criteria Ranking

Main criteria	weights	Sub-criteria	Weights	Global weight	Global rank
Economic	0.448	Trade credit	0.298	0.1335	1
		Cash management	0.263	0.1178	4
		Inventory control	0.139	0.0622	6
		Raw material procurement	0.232	0.1039	5
		Service delivery management policies	0.066	0.0296	12
Social	0.399	Stakeholder engagement	0.0296	0.1180	2
		Stakeholder empowerment	0.140	0.0559	8
		Stakeholder and customer satisfaction	0.295	0.1178	3
		Stakeholder regulations	0.154	0.0614	7
		Buyer-supplier partnership	0.066	0.0263	13
Environment	0.151	Environmental policy	0.319	0.0482	10
		Reduce, reuse, and recycle of energy and wastewater	0.358	0.054	9
		Environmental costs	0.118	0.0178	14
		Green technology	0.203	0.031	11

[DOI: 10.71885/ijorlu-2024-1-680]

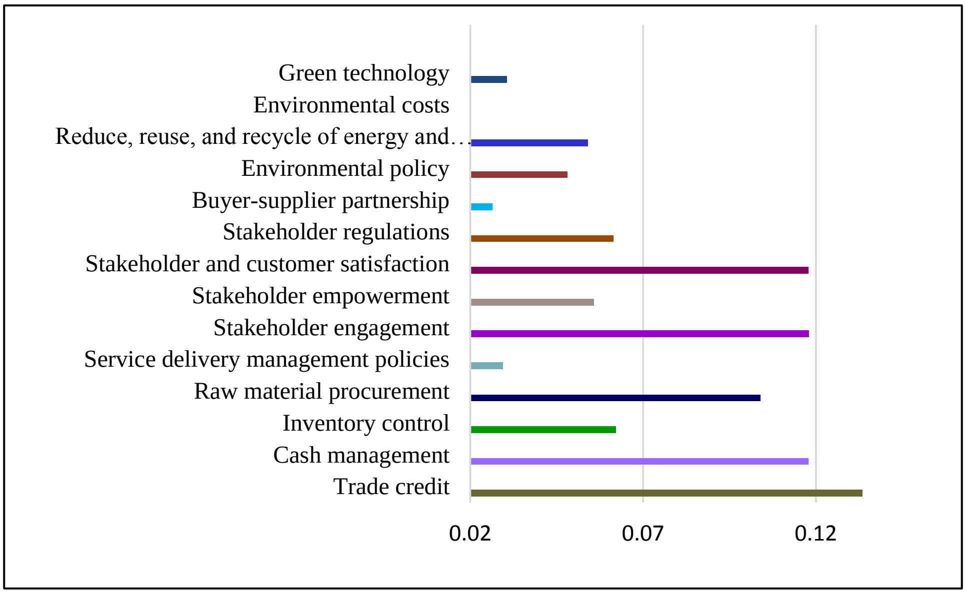

Fig 2 Sub-criteria global ranking related to sustainable supply chain financing

In this stage, the main criteria were compared using the GAMS software, and based on the results, Economic, Social and Environment ranked first to third, respectively. In the next stage, all the sub-criteria were compared, and based on the results, Trade credit, Stakeholder engagement and Stakeholder and customer satisfaction achieved ranks one to three, respectively. Based on the results, in this study, three key factors that significantly impact organizational success were identified: trade credit, stakeholder engagement, and stakeholder and customer satisfaction. Trade credit was highlighted for its role in facilitating cash flow and improving financial relationships, stakeholder engagement for its importance in maintaining effective and continuous communication with various groups, and stakeholder and customer satisfaction for its direct impact on loyalty and long-term success. These factors are crucial in driving sustainable growth and optimizing organizational performance.

3.4 Findings Based on the BWM Method

Research Question 1: What are the most important dimensions of sustainable supply chain finance?

In the first stage, based on the obtained analyses, the economic, social, and environmental criteria were ranked. In the second stage, the economic sub-criteria were examined, and Trade credit first, followed by Cash management, raw material procurement, Inventory control, and Service delivery management policies ranks. In the third stage, all criteria were compared and ranked. In this comparison, Trade credit ranked first, Stakeholder engagement ranked second, and Stakeholder and customer satisfaction ranked third.

Research Question 2: How is the prioritization of Industry 4.0 technologies related to sustainable supply chain finance?

This question was addressed in three stages:

First, the overall weights of the criteria were determined and ranked. Second, the weights of the sub-criteria were analysed, and the sub-criteria within each category were prioritized.

[DOI: 10.71885/ijorlu-2024-1-680]

Third, the overall weights of all sub-criteria were compared and ranked. In the first stage, the results from the BWM method showed that information technology was the most important criterion, followed by operational technologies, customer related technologies, and financial technologies in subsequent ranks. In the second stage, the sub-criteria of information technologies were ranked. Internet of Things (IoT) emerged as the most important factor, followed by data analytics, cloud computing, and big data in subsequent positions. In the third stage, all criteria were compared and ranked. In this comparison, operation control and automation, Internet of Things (IoT), and data analytics ranked first, second, and third, respectively.

4 Managerial Implications

Based on the identification of the most important criteria and sub-criteria, the following practical recommendations are presented.

Automated Control and Process Automation:
Automated control and process automation significantly reduce costs and improve efficiency. These systems enhance the speed and accuracy of processes, reduce the risk of human errors, and help ensure the accuracy of information. Other advantages of this approach include reducing production, maintenance, and raw material costs, which contribute to the profitability and commercial credibility of companies. Automation also boosts productivity and reduces delivery times, leading to increased cash flow and customer satisfaction. By optimizing processes and making efficient use of resources, these systems help conserve natural resources and reduce environmental pollution. Additionally, they create new jobs and improve working conditions for employees. In general, automated control and process automation not only improve product quality but also strengthen positive relationships with suppliers and stakeholders.

Internet of Things (IoT):
The Internet of Things (IoT) helps companies improve their products and services by collecting data, which leads to increased quality, reduced costs, enhanced productivity, and shorter delivery times. This technology enables more precise monitoring and control of production and distribution processes, reducing resource waste and improving supply chain efficiency. Moreover, the use of sensors and smart devices lowers production and distribution costs while providing more accurate information to consumers, improving their experience and reducing costs.

Big Data:
Big Data helps improve algorithms and predictive models, optimizing production planning, distribution, and inventory management within the supply chain. By analysing production, warehousing, and transportation processes, Big Data enhances supply chain efficiency and reduces resource waste, contributing to environmental preservation. Additionally, by analysing customer data, companies can identify behavioural patterns and improve their services and products. This process supports data-driven decision-making, identifies new opportunities, reduces risks, and strengthens communication with stakeholders. Ultimately, Big Data can increase transparency and trust between stakeholders and the organization.

5 Conclusion

This research aimed to identify and prioritize Industry 4.0 technologies in relation to sustainable supply chain finance and assess their impact on its key dimensions. Through a literature review and the application of the Best-Worst Method (BWM), we developed two

[DOI: 10.71885/ijorlu-2024-1-680]

questionnaires to gather data on Industry 4.0 technologies and sustainable supply chain finance criteria. Data were analysed using GAMS software to determine the weight and rank of each criterion and sub-criterion. The results highlight automated control and process automation, the Internet of Things (IoT), and data analytics as the most impactful Industry 4.0 technologies for sustainable supply chain finance. Commercial credibility, stakeholder participation, and customer satisfaction emerged as the key factors for successful implementation of sustainable supply chain finance. These technologies enhance efficiency, profitability, and transparency within supply chains, enabling better decision-making, resource optimization, and improved customer experiences. This study contributes to the theoretical understanding of how Industry 4.0 technologies intersect with sustainability practices in supply chain finance. Future research could explore specific industry applications and the long-term effects of these technologies on supply chain resilience and sustainability. The main limitation of this research lies in its focus on a specific set of technologies and industries, suggesting the need for broader studies across various sectors.

Future research direction

• In this research, all technologies of Industry 4.0 were examined. One of the technologies from Industry 4.0 can be selected and its impact on sustainable supply chain financing can be studied in detail.
• This research was conducted in Gilan province. It could be carried out in larger and more industrial cities such as Tehran, Isfahan, and Mashhad.
• Evaluation of sustainable financing methods in the supply chain with an emphasis on sustainable supply chain financing.

References

1. Soni, G., Kumar, S., Mahto, R. V., Mangla, S. K., Mittal, M. L., & Lim, W. M. (2022). A decision-making framework for Industry 4.0 technology implementation: The case of FinTech and sustainable supply chain finance for SMEs. Technological Forecasting and Social Change, 180, 121686.
2. Jamwal, A., Agrawal, R., Sharma, M., Kumar, V., & Kumar, S. (2021). Developing A sustainability framework for Industry 4.0. Procedia cirp, 98, 430-435.
3. Beske-Janssen, P., Johnson, M. P., & Schaltegger, S. (2015). 20 years of performance measurement in sustainable supply chain management–what has been achieved?. Supply chain management: An international Journal, 20(6), 664-680.
4. Sim, J., & Prabhu, V. (2017). A microcredit contract model with a Black Scholes model under default risk. International Journal of Production Economics, 193, 294-305.
5. Kamble, S. S., Gunasekaran, A., Ghadge, A., & Raut, R. (2020). A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs-A review and empirical investigation. International journal of production economics, 229, 107853.
6. Abdel-Basset, M., Mohamed, R., Sallam, K., & Elhoseny, M. (2020). A novel decision-making model for sustainable supply chain finance under uncertainty environment. Journal of Cleaner Production, 269, 122324.
7. Jia, F., Zhang, T., & Chen, L. (2020). Sustainable supply chain Finance: Towards a research agenda. Journal of cleaner production, 243, 118680.
8. Clune, W. H., & Zehnder, A. J. (2020). The evolution of sustainability models, from descriptive, to strategic, to the three pillars framework for applied solutions. Sustainability Science, 15, 1001-1006.
9. Arora, N. K. (2018). Environmental Sustainability—necessary for survival. Environmental Sustainability, 1(1), 1-2.
10. Rosen, M. A. (2018). Issues, concepts and applications for sustainability. Glocalism: Journal of culture, politics and innovation, (3).

[DOI: 10.71885/ijorlu-2024-1-680]

11. Rajeev, A., Pati, R. K., Padhi, S. S., & Govindan, K. (2017). Evolution of sustainability in supply chain management: A literature review. Journal of cleaner production, 162, 299-314.
12. Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2017). Intelligent manufacturing in the context of industry 4.0: a review. Engineering, 3(5), 616-630.
13. Sommer, L. (2015). Industrial revolution-industry 4.0: Are German manufacturing SMEs the first victims of this revolution?. Journal of Industrial Engineering and Management, 8(5), 1512-1532.
14. Pereira, A. C., & Romero, F. (2017). A review of the meanings and the implications of the Industry 4.0 concept. Procedia manufacturing, 13, 1206-1214.
15. Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. Energies, 15(17), 6276.
16. Fan, J., Han, F., & Liu, H. (2014). Challenges of big data analysis. National science review, 1(2), 293-314.
17. Carayannis, E. G., & Morawska-Jancelewicz, J. (2022). The futures of Europe: Society 5.0 and Industry 5.0 as driving forces of future universities. Journal of the Knowledge Economy, 13(4), 3445-3471.
18. Brecher, C., Müller, A., Dassen, Y., & Storms, S. (2021). Automation technology as a key component of the Industry 4.0 production development path. The International Journal of Advanced Manufacturing Technology, 117, 2287-2295.
19. Tao, F., Xiao, B., Qi, Q., Cheng, J., & Ji, P. (2022). Digital twin modeling. Journal of Manufacturing Systems, 64, 372-389.
20. Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. International journal of production economics, 229, 107776.
21. Salodkar, A., Morey, K., & Shirbhate, M. (2015). Electronic wallet. International Research Journal of Engineering and Technology (IRJET), 2(09), 975-977.
22. Kacen, J. J., Hess, J. D., & Chiang, W. Y. K. (2013). Bricks or clicks? Consumer attitudes toward traditional stores and online stores. Global Economics and Management Review, 18(1), 12-21.
23. Chalmeta, R. (2006). Methodology for customer relationship management. Journal of systems and software, 79(7), 1015-1024.
24. Mukhopadhyay, U., Skjellum, A., Hambolu, O., Oakley, J., Yu, L., & Brooks, R. (2016, December). A brief survey of cryptocurrency systems. In 2016 14th annual conference on privacy, security and trust (PST) (pp. 745-752). IEEE.
25. Bag, S., Telukdarie, A., Pretorius, J. C., & Gupta, S. (2021). Industry 4.0 and supply chain sustainability: framework and future research directions. Benchmarking: An International Journal, 28(5), 1410-1450.
26. Mastrocinque, E., Ramírez, F. J., Honrubia-Escribano, A., & Pham, D. T. (2022). Industry 4.0 enabling sustainable supply chain development in the renewable energy sector: A multi-criteria intelligent approach. Technological Forecasting and Social Change, 182, 121813.
27. Naseem, M. H., & Yang, J. (2021). Role of industry 4.0 in supply chains sustainability: A systematic literature review. Sustainability, 13(17), 9544.
28. Manavalan, E., & Jayakrishna, K. (2019). A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. Computers & industrial engineering, 127, 925-953.
29. Rezaei, J. (2015). Best-worst multi-criteria decision-making method. Omega, 53, 49-57.
30. Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega, 64, 126-130.

[DOI: 10.71885/ijorlu-2024-1-680]