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Strategies for Green Supply Chain for Agriculture Equipment Manufacturing Industries: Perspective of Blockchain- IoT Integrated Architecture

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Abstract

In order to protect the environment, manufacturing sectors have begun implementing a green supply chain (GSC) strategy. Governments are enacting increasingly stringent environmental regulations; consequently, industries must reduce the environmental impact of their supply chains. Our research investigates the barriers to implementing a GSC in the agriculture equipment manufacturing industries (AEMI). This research aims to discover and prioritize the barriers that impede the implementation of sustainable supply chain strategies in the AEMI. Through an in-depth literature review, contributions from experts, and empirical analysis, seventy-one barriers are identified across ten categories. The top barrier in each category is determined using the Delphi approach. The Fuzzy Technique for Order of Preference by Similarity to the Ideal Solution (F-TOPSIS) method creates an exhaustive framework that evaluates and ranks these barriers. The top five barriers are the lack of an environmental partnership with buyers and suppliers, the design complexity when reusing or recycling old goods or products, carbon emissions, paint shop emissions, lack of environmental education and training professionals that lack the necessary skills and less manpower available for the greening supply chain. This framework facilitates decision-makers to organize resources and create effective strategies for overcoming identified barriers. In addition, we proposed a blockchain IoT integrated architecture and strategies. This integrated architecture and strategies will help to mitigate all GSC barriers. It also increases the supply chain's transparency, traceability and effectiveness, fostering sustainability practices and reducing environmental impacts. Blockchain and IoT facilitate real-time data collaboration, computerized transactions and the implementation of smart contracts, thereby enhancing cooperation, trust and collaboration among stakeholders. Implementing GSC practices enables manufacturers to reduce waste and increase productivity, thereby saving funds. In addition, adopting sustainable practices improves these industries' reputation and brand image among environmentally conscious customers, investors and other stakeholders.

Keywords- Green supply chain (GSC), Barriers of GSCM, Agriculture equipment manufacturing industries (AEMI), MCDM-Fuzzy TOPSIS method, Environmental sustainability, Blockchain technology, Internet of things (IoT) etc.

Nomenclature and Abbreviations

The **Table 1** displays the nomenclatures and abbreviations utilized in the research.

Table 1. Nomenclature and abbreviations.

Abbreviation	**Full meaning**
GSC	Green Supply Chain
AEMI	Agriculture Equipment Manufacturing Industry
F-TOPSIS	Fuzzy Technique for Order of Preference by Similarity to the Ideal Solution
IoT	Internet of Things
A*	Fuzzy Positive Ideal Solutions
A-	Fuzzy Negative Ideal Solutions
di*	Separation from Fuzzy Positive Ideal Solutions
di^-	Separation from Fuzzy Negative Ideal Solutions
CC_i	Closeness Coefficient

1. Introduction

The focus on sustainability and environmental responsibility has recently significantly changed manufacturing industries, especially in AEMI (Dubey et al., 2020). With the increasing consumer environmental consciousness and stricter governmental regulations, businesses must reduce the environmental effects of their supply chains (Ada, 2022). GSC approaches in the manufacturing sector are critical for increasing sustainability and minimizing environmental impact (Dubey et al., 2019). By implementing GSCM in their businesses, manufacturing sectors concentrate on cleaner production and greener techniques to address environmental challenges (Govindan et al., 2014). Because the market is unstable and has a wide variety of products, there is a continual need for innovation in products, processes, and management to implement and adopt sustainable initiatives (Gupta and Barua, 2018). There is an increasing need for governments and politicians also to enact policies to enhance societal sustainability through improved resource management and the establishment of closed-loop systems in the various stages of product development, utilization and disposal (Govindan and Hasanagic, 2018; Pieroni et al., 2019). An efficient, practical, cost-effective approach to ecologically sustainable practices must be recognized as a closed-loop and collaborative SCM. Most of the aim will be accomplished by combining a closed-loop supply chain with GSCM (Olugu et al., 2011; Madenas et al., 2015).

However, multiple barriers stand in the way of effectively implementing these GSC principles in manufacturing industries (Dhull and Narwal, 2016). The conventional supply chain confronts several barriers: cost, complexity, vulnerability, and unpredictability. The supply chains must be smarter if these issues are to be solved (Abdel-Basset et al., 2018). With technology improvements, integrating IoT and blockchain has emerged as an effective strategy for dealing with these barriers and improving GSC's efficiency, efficacy, authenticity, and transparency (Garrido-Hidalgo et al., 2019; Manavalan and Jayakrishna, 2019). Industry 4.0, CE, and GSCM are new sustainable development ideas that raise industries' economic and environmental performance (Ghisellini et al., 2016). Blockchain technology is increasingly being adopted across GSC due to the growing demand for increased trust. Improved transparency and traceability, digitalization of supply chains, increased data security, and utilization of smart contracts are key areas where these technologies provide significant value for GSCM (Saberi et al., 2019; Wang et al., 2019). Furthermore, incorporating big data analytics, machine learning (ML), and artificial intelligence (AI) in GSCM can play a crucial role in operational management, predictive logistics, handling hazardous material and enhancing environmental standards with advanced analytics and forecasting capabilities rate (Baryannis et al., 2019; Kantasa-ard et al., 2019; Mao et al., 2019; Prahathish et al., 2020; Dwivedi et al., 2021).

Despite technological advancements, there is a lack of research on their application in AEMI's green supply chain. This oversight is mainly due to a research gap exploring unique barriers to GSC adoption in AEMI. In addition, it is necessary to use MCDM Fuzzy TOPSIS methodologies to prioritize these barriers. Although the capabilities of blockchain and IoT technologies to improve supply chain transparency have been acknowledged, there is a lack of research on their combined use to develop architectures and strategies for GSCM in AEMI. As a result, these barriers hinder the successful implementation of GSC practices in AEMI. Therefore, this research aims to identify and prioritize the barriers to implementing GSC practices in AEMI. It proposes developing a blockchain-IoT integrated architecture and formulating specific blockchain-IoT-based strategies to overcome these barriers, ensuring the success of GSC initiatives in the AEMI. By adopting a comprehensive approach, this study seeks to significantly contribute to the existing body of knowledge, offering practical solutions and strategies for AEMI to advance toward more sustainable and environmentally responsible supply chain practices.

The research paper is structured into various sections to methodically tackle the barriers to GSCM in the AEMI by applying blockchain and IoT technologies. The paper starts with a thorough literature review from 2005 to 2023, focusing on identifying barriers to GSCM and the impact of Industry 4.0 technologies. Subsequently, we describe the methodology utilized for this study, incorporating input from expert consultations to frame the research objectives and fill the research gaps identified through the literature. We used the Fuzzy TOPSIS method to prioritize the seventy-one identified barriers to GSCM. After analysing the prioritization results, we developed an innovative blockchain-IoT integrated architecture to mitigate these barriers effectively. In the subsequent sections, we developed specific strategies for each identified barrier, showcasing how integrating blockchain and IoT technologies can enhance sustainability within the AEMI's GSC. The paper concludes by summarizing our findings and outlining future research directions, providing a thorough resource for practitioners and researchers focused on enhancing GSCM with technology.

2. Literature Survey

Several publications from prestigious and well-known publishers were reviewed for comparison. The papers were categorized into several areas on a broad scale, and the survey effectively emphasizes and illustrates the significance of our research study.

2.1 Green Supply Chain Management

Liu et al. (2016) examined supply chain capabilities by adopting different green initiatives. Concerning sustainability practices, green buying, and green design, SCCs play a vital role in the execution of green strategies. Maria Vanalle and Blanco Santos (2014) identified and analysed the aspects like environmental, financial, and operational performance taken into account in sustainability. They assessed methods for minimizing or eliminating the usage of toxic materials. Govindan et al. (2014) highlighted barriers to implementing GSCM in industrial sectors. Mathiyazhagan et al. (2013) and Drohomeretski et al. (2014) discovered the most significant barrier to implementing GSCM in Indian auto component manufacturing enterprises. Gupta and Barua (2018) analysed the barriers that hinder the successful implementation of GSCM practices within small and medium-scale enterprises.

Mathivathanan et al. (2018) investigated the interconnected impacts of SSCM techniques in the automobile sector. They provide opinions from various stakeholders, including associations for management, the environment, society, and government. Koplin et al. (2007) developed a methodological approach to integrating social and environmental standards within supply policy and management. Madenas et al. (2015) measured and prioritized the perceived relevance of issues in the supply chain pertaining to information flow in the context of product development. They discovered that poor information systems are responsible for around half of the barriers identified. Charan (2012) also investigated GSC performance endeavours and their impact on automobile manufacturing, emphasizing the necessity for a comprehensive strategy and addressing challenges such as vendor performance assessment. Blos et al. (2009) emphasized supply chain risks within Brazil's automobile and electronics industries. Thakker and Rane (2018) provide a validated process model for green supplier development in the Indian auto sector. This study offers valuable practical insights for managers and presents new opportunities for further research in GSCM.

2.2 Circular Economy (CE) and GSCM

According to Kazancoglu et al. (2018), integrating the circular economy (CE) concept into GSCM can be achieved by effectively managing economic, environmental, logistical, organizational, and marketing performance measures to establish an optimal equilibrium. Geissdoerfer et al. (2018) examined and developed a comprehensive framework to evaluate the sustainability performance of CE and GSCM practices in industrial implementation. Batista et al. (2018) establish sustainable supply chain narratives, including reverse logistics, closed-loop and GSC. Gaustad et al. (2018) examined the methods employed by various organizations in analyzing and monitoring their susceptibility to essential material supply chain difficulties. Additionally, the researchers provided concrete business illustrations to demonstrate the implementation of CE. The findings of their study indicate the potential for risk reduction that might be achieved with the use of recycling processes. Genovese et al. (2017) and Zeng et al. (2017) have revealed that institutional pressure plays a significant role in shaping the development of supply chain relationships and the design of SSCM. Zhu et al. (2007) analysed GSCM techniques in the Chinese auto sector, focusing on automotive firms' pressures, initiatives, and performance. The analysis demonstrates a need for more excellent GSCM implementation throughout the supply chain to generate considerable economic and environmental advantages.

2.3 Barriers to GSCM

The barriers to GSCM and its explanation are shown in **Table 2**.

Table 2. Barriers in GSCM of AEMI.

S. No.	Category	Barriers	Explanation	Authors
1.	Strategic	B-1 Less manpower for greening supply chain	This barrier comes from a shortage of trained employees with knowledge of environmentally friendly and sustainable procedures, technology, and laws.	Barve and Muduli (2013), Govindan et al. (2014), Dhull and Narwal (2016), Kaur et al. (2017), Kaur and Awasthi (2018), Majumdar and Sinha (2018), Kaur et al. (2019), Rahman et al. (2020).
		B-2 Lack of communication cooperation between departments	It is challenging to align sustainability goals, share information and coordinate actions when different organizational departments cannot communicate efficiently. It may result in arbitrary decision-making, repetition of effort, and a loss of chances to improve environmental performance.	Govindan et al. (2014), Mathiyazhagan et al. (2016), Malviya and Kant (2018), Kaur et al. (2019).
		B-3 GSCM is not well understood by employees	Employee support and participation in eco-friendly activities are hampered when they are unaware of GSCM concepts and advantages**.**	Govindan et al. (2014), Kaur et al. (2017), Malviya and Kant (2018), Kaur et al. (2019), Tumpa et al. (2019), Rahman et al. (2020), Sajjad et al. (2020).
		B-4 GSCM and the supply chain process are not interconnected	It becomes difficult to successfully implement green programmes and meet environmental goals without effortless incorporation and integration of GSCM concepts within the supply chain.	Govindan et al. (2014), Tay et al. (2015), Mathiyazhagan et al. (2016), Kaur et al. (2017), Kaur et al. (2019).
		B-5 Lack of government support for environmentally friendly policies	It becomes easier for these industries to invest in sustainable technology, implement eco-friendly practices, and manage the transition to a greener supply chain with appropriate legislation, rewards, and support from government agencies.	Jayant and Azhar (2014), Dhull and Narwal (2016), Kaur et al. (2017), Majumdar and Sinha (2018), Kaur et al. (2019).

Table 2 continued…

		B-6 Insufficient assistance and direction from regulatory agencies	These industries find negotiating and complying with sustainability standards challenging without specific instructions, motivations, and enforcement mechanisms, slowing their development towards a more environmentally friendly supply chain.	Govindan et al. (2014), Tay et al. (2015), Kaur et al. (2017).
		B-7 Lack of benchmarking system	With an organised framework for assessing environmental performance, it is easier to recognise problem areas, set goals, and promote ongoing sustainability improvements within the sector.	Majumdar and Sinha (2018), Kaur et al. (2019), Rahman et al. (2020), Sajjad et al. (2020).
		B-8 Absence of a Green performance evaluation system	With a structured mechanism for monitoring and maintaining track of environmental performance, it is easier to evaluate improvements and areas for development and successfully incorporate sustainable practices into the entire manufacturing system.	Govindan et al. (2014), Mathiyazhagan et al. (2016), Tseng et al. (2019).
		B-9 Fluctuating market demand/ market competition and uncertainty	Forecasting and preparing for sustainable procedures can be difficult due to the volatile nature of market demand and fierce competition	Balon et al. (2016), Dhull and Narwal (2016), Tumpa et al. (2019).
		B-10 Fear of failure in establishing a GSC	Adopting sustainable practices may need to be improved by concerns about the costs, hazards, and uncertainties related to their implementation.	Govindan et al. (2014), Wang et al. (2016), Kaur et al. (2019), Rahman et al. (2020).
		B-11 Insufficient awareness of the environmental consequences for industries	Businesses may only value the significance of implementing eco-friendly initiatives if they know the possible adverse effects of unsustainable practices, such as loss of resources and pollution**.**	Barve and Muduli (2013), Jayant and Azhar (2014), Kaur et al. (2019).
2.	Financial	B-12 Less financial resources available	Investments in environmentally friendly practices, purchasing eco-friendly materials, and developing sustainable technology can all be hampered by a lack of financial resources.	Govindan et al. (2014), Tay et al. (2015), Balon et al. (2016), Dhull and Narwal (2016), Kaur et al. (2017), Malviya and Kant (2018), Kaur et al. (2019), Sajjad et al. (2020).
		B-13 Large investments with little return on capital	High investments and less return-on investments may be outweighed by the considerable up-front costs associated with putting green practices into practice, such as updating manufacturing methods and investing in sustainable technologies.	Govindan et al. (2014), Dhull and Narwal (2016), Wang et al. (2016), Kaur et al. (2017), Moktadir et al. (2018), Majumdar and Sinha (2018), Kaur et al. (2019), Tumpa et al. (2019), Bai and Satir (2020).
		B-14 High GSC cost and Greening cost	Implementing sustainable practices, such as procuring eco-friendly products and investing in renewable energy, might cost more than conventional supply chain strategies.	Govindan et al. (2014), Dhull and Narwal (2016), Malviya and Kant (2018), Moktadir et al. (2018), Majumdar and Sinha (2018), Rahman et al. (2020), Bai and Satir (2020).
		B-15 High amount of expenditure for collecting and recycling used products	Infrastructure development for recycling used products can come at a high cost, including collecting systems, transportation, and storage.	Govindan et al. (2014), Kaur et al. (2017), Kaur et al. (2019), Tumpa et al. (2019), Uddin et al. (2019).
		B-16 More cost of environment-friendly packaging	Compared to traditional packaging alternatives, the costs of obtaining sustainable resources, creating eco-friendly packaging and putting green packaging solutions into operation might be higher.	Govindan et al. (2014), Dhull and Narwal (2016), Wang et al. (2016), Kaur et al. (2019).
		B-17 High expense of disposing of hazardous materials	Highly hazardous waste created during manufacturing might have high costs associated with its correct disposal.	Tay et al. (2015), Wang et al. (2016), Majumdar and Sinha (2018), Kaur et al. (2019), Tseng et al. (2019), Uddin et al. (2019), Rahman et al. (2020).

Table 2 continued…

		B-18- Lack of bank funding to promote environmentally friendly practices	The investment in environmentally friendly practices, energy-efficient machinery, and sustainable technology must be improved by the lack of bank financing designed for such endeavours.	Govindan et al. (2014), Kaur et al. (2019), Rahman et al. (2020).
		B-19 More cost required for switching to CE	It takes substantial expenditures in recycling facilities, design of goods, and recycling procedures to switch from a linear to a circular model, emphasising minimising waste and maximising resource efficiency.	Majumdar and Sinha (2018), Kaur et al. (2019), Tseng et al. (2019).
3.	Organizational and management	B-20 Lack of engagement and commitment from upper management	When top management is not actively involved or does not prioritise sustainability activities, it is difficult to get the required funding, promote cultural change, and set precise environmental performance standards.	Barve and Muduli (2013), Jayant and Azhar (2014), Tay et al. (2015), Balon et al. (2016), Dhull and Narwal (2016), Majumdar and Sinha (2018), Malviya and Kant (2018), Rahman et al. (2020).
		B-21 Inadequate cross-functional organization	It is challenging to align sustainability goals, incorporate green practices into diverse processes, and ensure continuous execution throughout the supply chain when there is a lack of collaboration and coordination between various divisions and roles within the organization.	Barve and Muduli (2013), Govindan et al. (2014), Kaur et al. (2017), Bai and Satir (2020).
		B-22 Absence of explicit norms, regulations, and procedures	It is challenging to develop consistent practices, monitor environmental performance, and assure adherence to criteria for sustainability without established standards and regulations.	Malviya and Kant (2018), Kaur et al. (2019), Tumpa et al. (2019), Uddin et al. (2019), Rahman et al. (2020).
		B-23 Insufficient organizational resources to provide sufficient GSCM	Adopting sustainable green practices, investments in green technology, and staff capacity building may need more available financial, human, and technological resources.	Govindan et al. (2014), Dhull and Narwal (2016), Kaur et al. (2019), Bai and Satir (2020).
		B-24 The inability of the organization to carry out GSCM	Effectively implementing green initiatives becomes complicated when an organization needs more expertise, talents, and capacities to establish and maintain environmentally friendly processes in its supply chain.	Barve and Muduli (2013), Govindan et al. (2014), Dhull and Narwal (2016), Kaur et al. (2019).
		B-25 Absence from government programmes and interactions with government authorities connected to green projects.	Organizations may miss out on essential incentives, monetary advantages, and regulatory advice that can assist the adoption of sustainable practices if they do not actively participate in appropriate government programmes.	Govindan et al. (2014), Tay et al. (2015), Kaur et al. (2017), Majumdar annd Sinha (2018), Malviya and Kant (2018), Tumpa et al. (2019).
		B-26 Rewards for green ideas are not sufficient.	Employee motivation and desire to actively participate in sustainability initiatives are hampered when the rewards and incentives for presenting and implementing sustainable ideas are insufficient.	Barve and Muduli (2013), Tay et al. (2015), Kaur et al. (2017), Uddin et al. (2019), Rahman et al. (2020).
		B-27 Insufficient R&D and green innovation capacity	Creating and deploying sustainable technologies, processes, and products is more accessible when organizations need more R&D resources and competencies to drive sustainable innovation.	Kaur et al. (2017), Majumdar and Sinha (2018), Moktadir et al. (2018).
		B-28 Commercial and technological uncertainties and failure-related worries accompany green innovations.	Organizations may need help to embrace and invest in fully sustainable practices due to the uncertainties and risks related to implementing green innovations, such as the commercial feasibility of new technology and the fear of failure.	Govindan et al. (2014), Kaur et al. (2017), Moktadir et al. (2018), Kaur et al. (2019), Rahman et al. (2020).

Table 2 continued…

		B-29 Doubt about the environmental benefits	Organizations might only invest in green projects if they see and value how sustainable practices can benefit the environment.	Govindan et al. (2014), Kaur et al. (2017), Majumdar and Sinha (2018), Kaur et al. (2019), Tumpa et al. (2019).
4.	Technical	B-30 Lack of infrastructure supporting emerging technologies, such as environmental monitoring systems	The adoption and integration of modern monitoring technologies that can efficiently measure and control environmental performance are hampered by a lack of infrastructure.	Barve and Muduli (2013), Wang et al. (2016), Majumdar and Sinha (2018), Moktadir et al. (2018), Malviya and Kant (2018).
		B-31 Incapable of incorporating green advances created by others	Organizations may miss significant chances for progress and sustainability when they fail to incorporate and utilize green innovations offered by other organizations.	Barve and Muduli (2013), Govindan et al. (2014), Mathiyazhagan et al. (2016), Kaur et al. (2019).
		B-32 Design complexity when reusing or recycling old goods or products	It is challenging to properly disassemble different materials and extract value from discarded items when things are not developed with recycling and reuse in consideration.	Govindan et al. (2014), Kaur et al. (2017), Tumpa et al. (2019), Kaur et al. (2019), Majumdar and Sinha (2018), Rahman et al. (2020).
		B-33 Resistance to advance technology adoption	When there is opposition to implementing cutting-edge technology, such as smart devices for monitoring or energy production from renewable sources, it hampers the implementation of creative solutions that can enhance sustainability.	Barve and Muduli (2013), Jayant and Azhar (2014), Wang et al. (2016), Moktadir et al. (2018), Malviya and Kant (2018).
		B-34 Insufficient competence in technology	Incorporating green initiatives into enterprises becomes more manageable when those organizations need more knowledge and abilities to deploy environmentally friendly techniques and technology.	Govindan et al. (2014), Tay et al. (2015), Wang et al. (2016), Moktadir et al. (2018), Tseng et al. (2019), Rahman et al. (2020).
		B-35 Complicated Operations	It is challenging to successfully incorporate and maintain sustainable practices when supply chain activities are complicated and confusing.	Barve and Muduli (2013), Govindan et al. (2014), Tay et al. (2015), Kaur et al. (2017), Majumdar and Sinha (2018).
		B-36 Consumption of hazardous/toxic materials	Hazardous materials are used in production, which causes damage to the environment and poses hazards to humans.	Govindan et al. (2014), Moktadir et al. (2018), Tumpa et al. (2019), Kaur et al. (2019), Rahman et al. (2020).
		B-37 More Inventory	Resource use, waste production, and carbon emission levels all rise when inventory is excessed.	Moktadir et al. (2018), Kaur et al. (2019), Tseng et al. (2019), Uddin et al. (2019).
		B-38 Lack of knowledge about modern technologies	Organizations find it difficult to embrace and incorporate the most recent sustainable technologies into their operations when they are ignorant about or untrained with modern technologies.	Barve and Muduli (2013), Kaur et al. (2017), Moktadir et al. (2018), Malviya and Kant (2018), Uddin et al. (2019), Rahman et al. (2020).
5.	Social-Cultural	B-39 Employees lack of dedication and trust	The embrace and successful implementation of environmentally friendly guidelines are hampered when employees are not entirely dedicated to sustainable development objectives and do not believe that green efforts are beneficial.	Barve and Muduli (2013), Govindan et al. (2014), Tay et al. (2015), Majumdar and Sinha (2018), Tumpa et al. (2019), Sajjad et al. (2020).
		B-40 Inadequate organizational green culture	The integration and implementation of green practices are hampered when there is a lack of understanding, dedication, and support for sustainability inside the business.	Barve and Muduli (2013), Govindan et al. (2014), Kaur et al. (2017), Moktadir et al. (2018), Kaur et al. (2019).
		B-41 Lack of environmental education and training professionals that lack the necessary skills	Employee's lack of expertise and knowledge in sustainable development hinders the efficient adoption and implementation of green initiatives.	Balon et al. (2016), Dhull and Narwal (2016), Majumdar and Sinha (2018), Moktadir et al. (2018), Malviya and Kant (2018), Tumpa et al. (2019).
		B-42 Lack of knowledge about environmental practices	The green initiative may need more awareness of environmentally friendly procedures.	Govindan et al. (2014), Tseng et al. (2019), Rahman et al. (2020), Sajjad et al. (2020).

Table 2 continued…

		B-43 Lack of GSCM adoption support, encouragement and drive from employees	The adoption of GSCM procedures is hampered when employees lack interest and excitement.	Barve and Muduli (2013), Govindan et al. (2014), Malviya and Kant (2018), Tumpa et al. (2019), Rahman et al. (2020).
		B-44 Lacking the authority to work for GSCM	Inadequate authority hampers decision-making power, resource distribution, partnership and legal compliance and can result in opposition to change.	Kaur et al. (2017), Kaur et al. (2019), Sajjad et al. (2020).
		B-45 Lack of integrity and corporate social responsibility	Organizations lacking a sense of corporate social responsibility and morality may emphasize short-term profits above sustainability.	Barve and Muduli (2013), Jayant and Azhar (2014).
		B-46 Difficulty in identifying environmental opportunities	The AEMI is complicated, with various stakeholders, different processes, and long product life cycles, making it difficult to pinpoint particular areas for sustainable development.	Balon et al. (2016), Majumdar and Sinha (2018), Kaur et al. (2019), Rahman et al. (2020).
6.	Buyer and Supplier	B-47 Lack of an environmental partnership with buyer and suppliers	Integrating strategy, exchanging information, and collaboratively moving towards GSC practices is challenging without a strong partnership between buyer and supplier committed to environmentally friendly objectives.	Majumdar and Sinha (2018), Malviya and Kant (2018), Kaur et al. (2019), Tumpa et al. (2019), Bai and Satir (2020).
		B-48 Unreliable supplier commitment	Unreliable supplier commitment might appear in several ways, including an uneven commitment to green programs, a lack of transparency in their GSC, or inadequate investment in sustainable technology.	Govindan et al. (2014), Tay et al. (2015), Dhull and Narwal (2016), Majumdar and Sinha (2018), Moktadir et al. (2018), Tumpa et al. (2019), Bai and Satir (2020).
		B-49 Lack of confidence among suppliers	This barrier appears when suppliers lack confidence in the demand for and marketing viability of sustainable activities and products. Suppliers may be aware of investing in sustainable technology or implementing green practices due to uncertainty over consumer preferences, demand, and monetary benefits.	Moktadir et al. (2018), Malviya and Kant (2018), Kaur et al. (2019), Bai and Satir (2020), Rahman et al. (2020).
		B-50 Supplier resistance to GSCM change	Suppliers may be unwilling to implement green initiatives because of fears about higher costs, unfamiliarity with environmentally friendly processes and a lack of perceived rewards.	Barve and Muduli (2013), Govindan et al. (2014), Dhull and Narwal (2016).
		B-51 The inability of the firm and its suppliers to work together	It might be due to a lack of communication, a conflicting goal or a lack of mutual understanding of and dedication to sustainability goals.	Govindan et al. (2014), Moktadir et al. (2018), Kaur et al. (2019), Bai and Satir (2020).
		B-52 Lack of knowledge regarding GSCM among customers	It emerges when consumers are unaware of the environmental implications of the products they purchase and sustainable GSCM**.**	Dhull and Narwal (2016), Majumdar and Sinha (2018), Moktadir et al. (2018), Tumpa et al. (2019).
		B-53 Lack of supplier understanding of environmental issues	Finding sustainable materials and using sustainable methods are difficult when suppliers lack knowledge or awareness of environmental issues.	Govindan et al. (2014), Balon et al. (2016), Kaur et al. (2017), Majumdar and Sinha (2018).
		B-54 Failure anxiety among suppliers	Suppliers may be cautious about adopting sustainable methods because they fear failing to develop and manage sustainable processes. They may be anxious about rising costs, changes in manufacturing processes, or uncertainty in satisfying environmental regulations.	Balon et al. (2016), Tseng et al. (2019), Bai and Satir (2020), Rahman et al. (2020), Sajjad et al. (2020).
		B-55 Lack of information exchange and communication about GSCM	When stakeholders, such as manufacturers, suppliers and customers, fail to communicate and share information, it becomes difficult to successfully adopt and coordinate sustainable practices.	Barve and Muduli (2013), Govindan et al. (2014), Tay et al. (2015), Moktadir et al. (2018), Kaur et al. (2019).
		B-56 Measurement and monitoring of the environmental practices of suppliers are difficult.	Assessing and tracking suppliers' environmental performance can be difficult due to various variables, such as various suppliers, a lack of established measures, and restricted access to reliable information.	Govindan et al. (2014), Dhull and Narwal (2016), Kaur et al. (2017), Rahman et al. (2020), Bai and Satir (2020).

Table 2 continued…

7.	Logistics	B-57 Long vehicles routes	Longer routes for transportation result in higher fuel costs, more significant carbon emissions, and less effective logistics.	Govindan et al. (2014), Tseng et al. (2019), Kaur et al. (2019).
		B-58 Long Distance travelled,	When resources and goods need to be carried across long distances, it affects the environment because more fuel is used and more emissions are produced.	Govindan et al. (2014), Kaur et al. (2017), Kaur et al. (2017).
		B-59 Absence of awareness about reverse logistics	Successful management of product return, reuse, recycling and waste reduction is hampered when industries are unaware of the advantages and practices of reverse logistics.	Govindan et al. (2014), Jayant and Azhar (2014), Balon et al. (2016), Wang et al. (2016), Kaur et al. (2017), Kaur et al. (2019).
8.	Legislation	B-60 Absence of environmental policy for GSCM	Sustainable methods are complex for manufacturers since no defined rules or guidelines exist.	Barve and Muduli (2013), Govindan et al. (2014), Balon et al. (2016), Moktadir et al. (2018), Tumpa et al. (2019).
		B-61 Lack of strict supervision and monitoring	It becomes challenging to guarantee adherence to environmental standards and sustainable practices across the supply chain without enough monitoring. The efficiency of green programs is hampered by this lack of control, which also raises the risk of violation.	Govindan et al. (2014), Wang et al. (2016), Moktadir et al. (2018), Tumpa et al. (2019).
		B-62 Lack of government support policy for GSCM	Without proper support from the government and laws, several organizations may experience challenges with establishing environmentally friendly practices in their supply chain activities.	Govindan et al. (2014), Malviya and Kant (2018), Moktadir et al. (2018), Tumpa et al. (2019), Rahman et al. (2020).
		B-63 Changing environmental regulations due to changing climate	Changing environmental regulations may also necessitate investments in new technology and infrastructure by industries to minimize their environmental impact and enhance energy efficiency.	Barve and Muduli (2013), Govindan et al. (2014), Kaur et al. (2017).
		B-64 Lack of enforcement	Some industries may ignore or avoid environmental laws and regulations without efficient enforcement.	Govindan et al. (2014), Tseng et al. (2019), Tumpa et al. (2019).
9.	Environmental	B-65 Carbon emission, paint shop emissions etc.	Manufacturing methods, transport, painting and energy use are common contributors to carbon and hazardous emissions in agriculture equipment manufacturing**.**	Tay et al. (2015), Kaur et al. (2017), Majumdar and Sinha (2018), Kaur et al. (2019), Rahman et al. (2020).
		B-66 Solid waste, wastewater from various manufacturing processes	Agriculture equipment manufacturing produces substantial solid waste, such as metallic scrap, packaging scraps, and other waste. It also produces sewage contaminated with chemical compounds, toxic substances, and oils.	Kaur et al. (2018), Kaur et al. (2019), Tseng et al. (2019), Rahman et al. (2020).
		B-67 Lack of recycling	Agriculture types of equipment are made from various materials, including plastic, metals, and rubber products, all of which may be recycled and utilized. On the other hand, the need for more suitable technology for recycling restricts the potential for reuse and recycling of these materials. As a result, manufacturers might turn to dumping or burning to dispose of waste materials, resulting in loss of resources and environmental damage.	Govindan et al. (2014), Kaur et al. (2017), Kaur et al. (2019), Rahman et al. (2020).
		B-68 Lack of water conservation	Cleaning, cooling, and machining processes require much water in agriculture equipment manufacturing.	Kaur et al. (2019), Tseng et al. (2019), Govindan et al. (2014).
		B-69 Lack of belief in the benefit to the environment	If stakeholders like vendors, producers, and workers do not believe in the ecological benefits of a GSC, they may be unwilling to embrace and invest in sustainable processes.	Jayant and Azhar (2014), Kaur et al. (2017), Moktadir et al. (2018), Rahman et al. (2020).
10.	Energy	B-70 Lack of energy conservation	Different manufacturing processes consume much energy.	Kaur et al. (2017), Moktadir et al. (2018), Kaur et al. (2019), Rahman et al. (2020).

Table 2 continued…

		B-71 More fuel consumption	Increasing fuel consumption causes more pollution, including air pollutants and particle matter. This not only has an impact on the surroundings, but it also poses health concerns to employees and the surrounding people.	Govindan et al. (2014), Moktadir et al. (2018), Kaur et al. (2019), Sajjad et al. (2020).

2.4 MCDM Fuzzy TOPSIS

Dandage et al. (2018) evaluated and ranked the numerous risk categories associated with multinational projects using the TOPSIS method. There are eight distinct categories of risks, with political, technological, and design risks being the most significant. Kirkire et al. (2018) applied the fuzzy TOPSIS approach to determine the relative importance of various risk factors in medical device development. The proposed methodology improves risk reduction and facilitates informed decision-making within the respective domain. Kirkire et al. (2020) used the FTOPSIS methodology to assess and rank the barriers hindering the local production of medical devices. Chaudhari et al. (2022) investigated and ranked adoption barriers for CE by using TOPSIS. Kirkire et al. (2020) used the FTOPSIS methodology to evaluate and rank the barriers affecting the local production of medical devices.

2.5 Industry 4.0 Technologies

Garrido-Hidalgo et al. (2019) identified and systematized many streams in applying control theory to operations and SCM to Industry 4.0 networks. Pasi et al. (2021) investigated the concept of Industry 4.0 within the context of Indian manufacturing. The authors aim to get a comprehensive knowledge of the motivators and enabling technologies that contribute to the sustainability of Industry 4.0 in the manufacturing sector. Muller and Voigt (2018) discovered issues, opportunities, and suggestions for integrating Industry 4.0 with the SCM. Luthra and Mangla (2018) identified significant barriers to Sector 4.0 activities and, by looking at the Indian manufacturing industry, assessed the identified critical difficulties to prioritize them for booming Industry 4.0 ideas for supply chain sustainability. Garrido-Hidalgo et al. (2019) provided a complete reverse SCM system built on collaboration between several IoT communication protocols, allowing cloud-based inventory monitoring. Manavalan and the conceptual framework model was developed by Manavalan and Jayakrishna (2019) using five essential SCM perspectives: industry, technology, environmental sustainability, cooperation, and organizational approach. They provide the standards that businesses may use to determine their level of preparation for the industry 4.0 revolution. Abdel-Basset et al. (2018) built a website for managers and vendors. Through RFID technology, they monitored the movement of goods at each level of the SCM process.

Kantasa-ard et al. (2019) suggested using regression models and neural network models to predict the trajectory of Thailand's consumption of white sugar in light of the current fluctuations in consumption. Dwivedi et al. (2021) recognized the importance of industry and society in the speed and direction of AI development. Fanoodi et al. (2019) used Artificial neural networks and auto-regressive integrated moving average models to forecast blood platelet needs to lessen supply chain unpredictability. Prahathish et al. (2020) also employed artificial neural networks to anticipate reasonably and somewhat minimize supply chain failures. Reducing inventory holdings is a significant factor in future decision-making policies in suggested architecture. Priore et al. (2019) used machine learning to assist managers in comprehending complicated inventory flow situations and improving the management of such circumstances.

Rane and Narvel (2022) presented an integrated architecture that combines blockchain and IoT technologies. This architecture has many benefits, including real-time data collection, autonomous resource coordination, decentralization, unreliable transactions, security, and transparency (Nagariya et al., 2022).

Baryannis et al. (2019) proposed an architecture for predicting supply chain risks utilizing data-driven AI approaches. Rane and Potdar (2021) proposed use cases for managers employing blockchain and Internet of Things technologies to facilitate stakeholder engagement. Pasi et al. (2020) examined the impact of IoT on the assembly line of a smaller-scale transformer manufacturer to increase efficiency, productivity, and safety. Rane et al. (2021a) also examined several techniques to improve the agility of Project Procurement Management. These strategies included using advanced technologies such as the IoT and blockchain. Cavalcante et al. (2019) used the data analytics capabilities of digital manufacturing to construct a whole fresh way to evaluate the risk profiles of supplier performance under uncertainty. Rane and Thakker (2020) analysed the utilization of blockchain and IoT technologies in the context of environmentally conscious procurement practices within supply chains. Saberi et al. (2019) used smart contracts and blockchain technology in SCM. Blockchain might help governments, communities, and consumers to meet sustainability targets. Rane et al. (2021a) devised a framework for managing project risks in heavy equipment manufacturing by leveraging IoT technology. The primary objective of this framework is to effectively address and reduce the many risks inherent in this industry. Pasi et al. (2020) developed a conceptual framework that utilizes IoT technology to improve efficiency and production across supply chain sectors. Wang et al. (2019) examined how future SCM activities and regulations are likely to be impacted by blockchain technology. Prasad et al. (2022) explore the potential of blockchain technology in addressing the barriers in the supply chain. Rane et al. (2021a) examined the potential benefits of integrating blockchain and IoT technologies in enhancing operational agility through real-time monitoring and predictive measures. However, blockchain technology has several challenges, such as intricacy, scalability, legal considerations, and limited knowledge (Kafeel et al., 2023). Panghal et al. (2022) established a regulatory framework to embrace blockchain to overcome challenges and promote its adoption and scalability in the food industry.

Finally, this literature review identifies the significant barriers to adopting a GSC in agricultural equipment manufacturing industries from an IoT-blockchain integrated architecture perspective. The identified barriers include Strategic, Organizational and management, technical, social-cultural, Buyer and Supplier, Logistics, Legislation, Environmental and Energy. Understanding and evaluating these barriers can give essential guidance for industry and government officials for overcoming barriers and encouraging the adoption of sustainable practices in the agricultural equipment manufacturing GSC.

2.6 Research Gaps

An extensive literature analysis of GSCM within the manufacturing sector shows that agricultural equipment manufacturers hold significant expectations for implementing GSCM practices. However, based on recent research and insights from industry experts, there needs to be more clarity surrounding the term GSCM. The present study discovered the following research gap.

(i) There is a lack of research for exploring and identifying barriers unique to AEMI, which may have distinct characteristics and complexities.
(ii) The literature lacks a comprehensive approach using MCDM to prioritize barriers of GSCM in AEMI.
(iii) Although the benefits of blockchain and IoT in enhancing supply chain transparency are acknowledged, research on their combined application in designing blockchain and IoT architectures for GSCM in AEMI to enhance sustainability is limited.
(iv) Insufficient research has been conducted on the formulation of innovative blockchain and IoT-based strategies to specifically address identified barriers and ensure the successful adoption of GSC within the AEMI.

2.7 Expert Inputs for Problem Definition

Expert inputs are essential in identifying research gaps in the field of GSCM in the AEMI. These inputs are collected via interviews and questionnaires. We have gained a deeper understanding of the specific gaps and challenges associated with adopting sustainable practices through integrating expert inputs and we have developed effective strategies for promoting sustainable GSCM. The subsequent following inputs arise during a conversation with professionals.

(i) A sufficient manpower needs to be available for greening the supply chain.
(ii) The concept of GSCM needs to be more structured and transparent.
(iii) The implementation of GSC necessitates an extensive investment.
(iv) The lack of government support and commitment to incorporating GSC practices into AEMI.
(v) Existing machines and infrastructure need to be improved for GSC transfer.

2.8 Problem Definition

The government and policymakers are compelling agriculture equipment manufacturers to implement GSC to protect the environment. Even so, understanding the GSC concepts remains ambiguous and implementing GSC within the micro and small-scale AEMI encounters multiple barriers. This study investigates and ranks barriers to GSC using the Delphi and MCDM Fuzzy TOPSIS techniques. Blockchain-IoT-based strategies and integrated architectures have been developed to overcome these barriers.

2.9 Research Objectives

(i) To explore the barriers that hinder implementing GSC practices in the AEMI.
(ii) To rank the barriers to GSCM in AEMI using MCDM-Fuzzy TOPSIS techniques to determine the most significant barriers.
(iii) To develop a blockchain-Internet of Things (IoT) integrated architecture to mitigate the barriers to GSCM in AEMI.
(iv) To develop blockchain-IoT-based strategies for addressing each barrier to prevent the failure of GSC in the AEMI.

3. Methodology

The methodology section introduces the outline of the methodology flowchart. Moreover, the study focuses on data collection, analyses barriers to GSCM, and utilizes Fuzzy-Topis Modeling to rank barriers to addressing the research problem.

3.1 Research Methodology Flowchart

The Research Methodology flowchart is shown **Figure 1**. The research on GSCM for AEMI will begin with a comprehensive literature review covering 2005 to 2023. This phase is divided into three major sections: a review of the literature on GSCM, a review of the prospective impact of Industry 4.0 on GSCM and a review of the barriers encountered in implementing GSCM. The research then accumulates expert input, which entails conducting interviews or surveys with field professionals to collect qualitative data and practical insights. Literature review and expert inputs identify and investigate barriers to adopting GSCM in the AEMI. These barriers are then ranked using the Fuzzy-TOPSIS method, which quantitatively evaluates their impact on GSCM implementation. The next phase is research findings, where all insights, evaluations, and analyses are compiled into an exhaustive report. The study then takes a technological turn with the developing blockchain- IoT integrated architecture section, which suggests how the IoT and blockchain could be used to improve GSCM practices. Based on these technological models and research findings, the final phase entails developing strategies for GSCM implementation in the AEMI. The study's conclusion summarises the main findings, strategies, recommendations and a roadmap for future research in this crucial area.

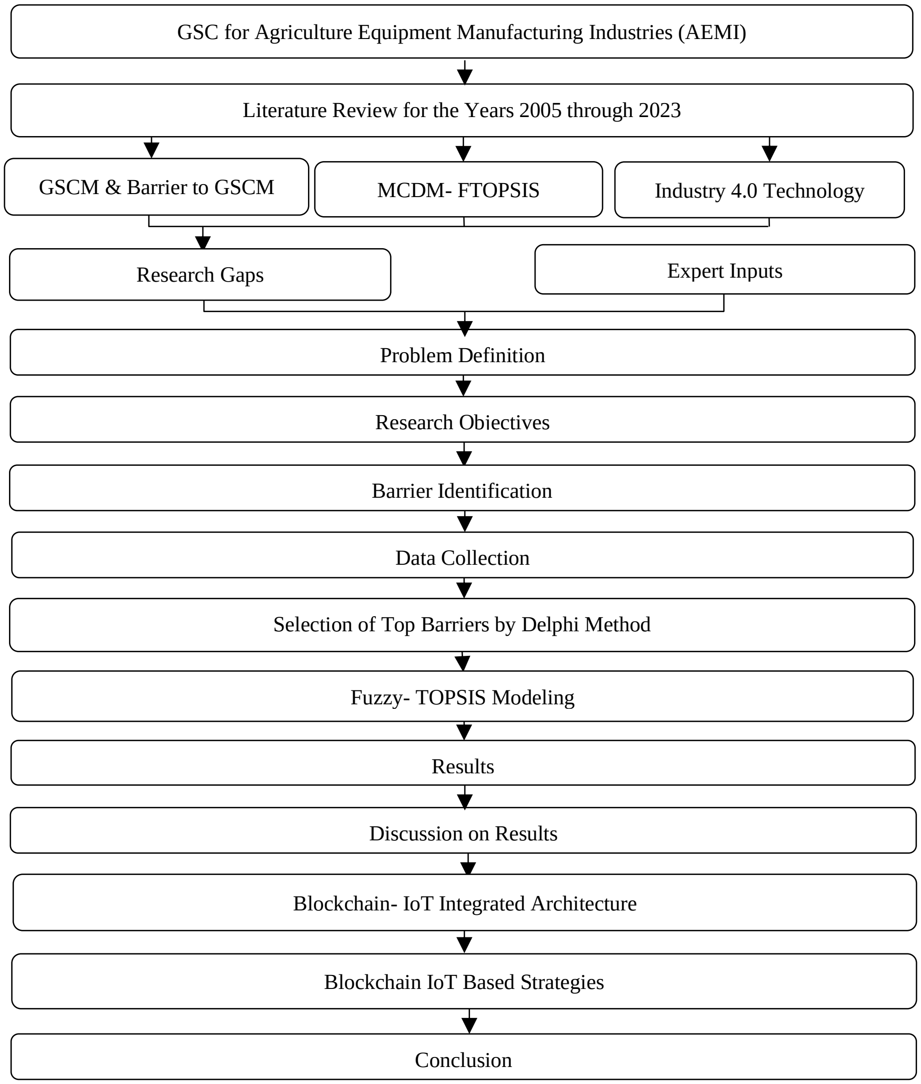

Figure 1. Research methodology flowchart.

3.2 Data Collection

(i) Systematic Sampling

A systematic sampling technique was implemented to select industry experts. This approach helps maintain the representation of various segments within the industry while being cost-efficient.

(ii) Sample Size Calculation

a) Initial Sample Size Calculation

The sample size for this research was determined based on the following equation:

$$n = \frac{z^2 \times p \times (1-p)}{E^2}.$$

where,
n = Sample size.
z = Z-score corresponding to the desired confidence level = 1.96 (95% confidence level).
P = Estimated proportion of the attribute being measured in the population=0.5.

In cases p is unknown, using 0.5 (50%) maximizes the sample size, as this value of p provides the maximum variance.

E = margin of error = 0.10 (for a 10% margin of error).

b) Finite Population Correction (FPC)

However, the population size is relatively small and close to the sample size, so FPC is applied to adjust the sample size, which is especially important when the sample size calculated initially is a significant fraction of the total population. The FPC was determined based on the following equation:

$$n_{\text{adjusted}} = \frac{n}{1+\left(\frac{n-1}{N}\right)} = 59.$$

where,
n_{adjusted} = adjusted sample size considering the finite population.
n = Initial sample size = 96.
N = total population size = 150.

The confidence level for the sample was set at 95%, leading to a calculated sample size of 59. This size is adequate to ensure that the characteristics of the data collected are representative of the population, within the tolerated margin of error, and suitable for the type of analyses planned for this research. Accordingly, the survey was conducted with 85 respondents.

3.3 Selection of Top Barriers by Delphi Method

We identified and selected 85 experts from the AEMI with good expertise. The sample data of experts is as shown in **Table 3**.

Table 3. Sample data of selected experts.

Sr. No.	Department	Designation	Experience in years	Type of products manufactured
1.	Manufacturing and Sales	CEO	12	Cultivator, plough, rotavators, tractor trolleys
2.	Manufacturing	Manger	13	Drip irrigation systems components.
3.	Manufacturing	CEO	8	All types of agriculture equipment's
4.	Sales	Manager	13	Agriculture Spray Blower

The questionnaire was developed by considering seventy one barriers to GSC in AEMI that include in different categories. Questions are framed to elicit expert opinions on the significance and impact of each barrier on the sustainability performance of AEMI. A five-point Likert scale is used for experts to rate the importance or relevance of each barrier within its respective category which is shown in **Table 4**.

Table 4. Likert scale.

Likert scale	Likert scale description
1	Strongly disagree
2	Disagree
3	Neutral
4	Agree
5	Strongly agree

A pilot test of the questionnaire is conducted with a subset of experts to identify any ambiguities, redundancies, and issues in question clarity. Questionnaires were modified based on feedback received during the pilot phase to enhance validity and reliability. Embarking upon the data collection phase, experts are invited to anonymously submit their ratings within stipulated timelines, fostering an environment conducive to candid deliberation. An iterative feedback loop underscores the Delphi process, wherein aggregated results are disseminated amongst experts for critical re-evaluation. Collected data was analyzed using Cronbach's alpha test to check its reliability. The Cronbach's alpha for this data was determined based on the following equation.

$$\alpha = \frac{\mathrm{K}}{\mathrm{K}-1}\left[1 - \frac{\sum \mathrm{s}^2\mathrm{y}}{\mathrm{s}^2\mathrm{x}}\right] = 0.91.$$

where,
α = Cronbach alfa.
K = No of items.
$\sum \mathrm{s}^2\mathrm{y}$ = Sum of the item variance.

The Cronbach alfa of 0.91 indicates excellent scale reliability and consistency. Based on responses collected from all experts, the top-scored barrier from each category is selected for further analysis, as shown in **Table 5**.

Table 5. Selected top ten barriers to GSCM in AEMI.

Sr. No.	Barriers
B1.	Less manpower available for greening supply chain
B2.	High green supply chain cost and greening cost
B3.	Insufficient organizational resources to provide sufficient GSCM
B4.	Design complexity when reusing or recycling old goods or products
B5.	Lack of environmental education and training professionals that lack the necessary skills
B6.	Lack of an environmental partnership with buyers and suppliers
B7.	Long distance travelled
B8.	Absence of environmental policy for GSCM
B9.	Carbon emissions, paint shop emissions etc.
B10.	More fuel consumption

3.4 Fuzzy- TOPSIS Modeling

Considering several criteria, the MCDM Fuzzy-TOPSIS methodology is employed to prioritize the barriers to GSCM in the AEMI. The process of applying Fuzzy-TOPSIS to rank barriers to GSCM involves the following steps:

***Step 1: Identification of the Decision Criteria*:** The relevant criteria for ranking the barriers of GSCM are identified. The criteria considered are sustainability (this criterion considers the long-term impact of addressing the barrier on the GSC and the environment), importance towards business (it includes enhancing brand reputation, compliance with regulations, customer satisfaction, market competitiveness, and long-term business viability), and cost-effectiveness (this criterion considers the costs associated with addressing the barrier and the potential benefits that can be achieved).

***Step 2: Assign Fuzzy Membership Functions*:** Three experts are selected as decision-makers. Experts are asked to assign fuzzy membership functions for each decision criterion to represent the degree of membership of each barrier to the criterion. For the criterion of the severity of the barrier, membership functions are assigned, such as very high, high, average, low and very low, as shown in **Table 6**.

Table 6. Fuzzy membership functions.

Criteria	**Sustainability**	**Importance towards business**	**Cost-effectiveness**	**Criteria**	**Sustainability**	**Importance towards business**	**Cost-effectiveness**	**Criteria**	**Sustainability**	**Importance towards business**	**Cost-effectiveness**
	Decision Maker-1				**Decision Maker-2**				**Decision Maker-3**		
B1	Very High	High	High	B1	High	High	Very High	B1	Very High	Very High	High
B2	High	High	Very High	B2	very High	High	Very High	B2	High	Very High	Very High
B3	Average	High	High	B3	High	High	High	B3	Average	High	High
B4	High	High	Average	B4	High	Very High	Average	B4	High	High	Low
B5	Very High	Very High	Low	B5	Very High	High	Average	B5	Very High	High	Average
B6	Very High	Very High	Low	B6	High	Very High	Average	B6	Very High	Very High	Low
B7	Very High	Average	Very High	B7	Very High	Average	Very High	B7	Very High	Average	Very High
B8	High	Low	Low	B8	High	Low	Low	B8	High	Low	Low
B9	Very High	Very High	Average	B9	Very High	Very High	Average	B9	High	Very High	Average
B 10	Very High	Average	Very High	B 10	High	Low	Very High	B 10	Very High	Average	High

The correlation between fuzzy membership function and fuzzy numbers is shown in **Table 7**.

Table 7. Fuzzy numbers.

Very High	7	9	9
High	5	7	9
Average	3	5	7
Low	1	3	5
Very Low	1	1	3

Fuzzy numbers are assigned to each decision criterion for each barrier to GSCM, as shown in **Table 8**.

Table 8. Assignment of fuzzy numbers.

Criteria	**Sustainability**			**Importance towards business**			**Cost-effectiveness**			**Criteria**	**Sustainability**			**Importance towards business**			**Cost-effectiveness**			**Criteria**	**Sustainability**			**Importance towards business**			**Cost-effectiveness**		
B1	7	9	9	5	7	9	5	7	9	B1	5	7	9	5	7	9	7	9	9	B1	7	9	9	7	9	9	5	7	9
B2	5	7	9	5	7	9	7	9	9	B2	7	9	9	5	7	9	7	9	9	B2	5	7	9	7	9	9	7	9	9
B3	3	5	7	5	7	9	5	7	9	B3	5	7	9	5	7	9	5	7	9	B3	3	5	7	5	7	9	5	7	9
B4	5	7	9	5	7	9	3	5	7	B4	5	7	9	7	9	9	3	5	7	B4	5	7	9	5	7	9	1	3	5
B5	7	9	9	7	9	9	1	3	5	B5	7	9	9	5	7	9	3	5	7	B5	7	9	9	5	7	9	3	5	7
B6	7	9	9	7	9	9	1	3	5	B6	5	7	9	7	9	9	3	5	7	B6	7	9	9	7	9	9	1	3	5
B7	7	9	9	3	5	7	7	9	9	B7	7	9	9	3	5	7	7	9	9	B7	7	9	9	3	5	7	7	9	9
B8	5	7	9	1	3	5	1	3	5	B8	5	7	9	1	3	5	1	3	5	B8	5	7	9	1	3	5	1	3	5
B9	7	9	9	7	9	9	3	5	7	B9	7	9	9	7	9	9	3	5	7	B9	5	7	9	7	9	9	3	5	7
B 10	7	9	9	3	5	7	7	9	9	B 10	5	7	9	1	3	5	7	9	9	B 10	7	9	9	3	5	7	5	7	9

Step* 3*: Construction of the Fuzzy Decision Matrix: The construction process involves assigning the degree of membership for each barrier to each decision criterion, utilizing the fuzzy membership functions established in Step 2. The combined decision matrix is shown in **Table 9**.

Table 9. Combined decision matrix.

Weights	7	9	9	5	7	9	3	5	7
Criteria	**Sustainability**			**Importance towards business**			**Cost-effectiveness**		
B 1	5	8.33	9	5	7.67	9	5	7.67	9
B 2	5	7.67	9	5	7.67	9	7	9	9
B 3	3	5.67	9	5	7	9	5	7	9
B 4	5	7	9	5	7.67	9	1	4.33	7
B 5	7	9	9	5	8.33	9	3	5	7
B 6	5	8.33	9	5	8.33	9	1	3.67	7
B 7	7	9	9	3	6.33	9	7	9	9
B 8	5	7	9	1	3	5	1	3	5
B 9	5	8.33	9	7	9	9	3	5	7
B 10	5	8.33	9	1	4.33	7	5	8.33	9

The decision matrix is normalized by considering all decision criteria, as shown in **Table 10**.

Table 10. Normalized fuzzy decision matrix.

Weights	7	9	9	5	7	9	3	5	7
Criteria	**Sustainability**			**Importance towards business**			**Cost-effectiveness**		
B 1	0.556	0.926	1.000	0.556	0.852	1.000	0.111	0.130	0.200
B 2	0.556	0.852	1.000	0.556	0.852	1.000	0.111	0.111	0.143
B 3	0.333	0.630	1.000	0.556	0.778	1.000	0.111	0.143	0.200
B 4	0.556	0.778	1.000	0.556	0.852	1.000	0.143	0.231	1.000
B 5	0.778	1.000	1.000	0.556	0.926	1.000	0.143	0.200	0.333
B 6	0.556	0.926	1.000	0.556	0.926	1.000	0.143	0.273	1.000
B 7	0.778	1.000	1.000	0.333	0.704	1.000	0.111	0.111	0.143
B 8	0.556	0.778	1.000	0.111	0.333	0.556	0.200	0.333	1.000
B 9	0.556	0.926	1.000	0.778	1.000	1.000	0.143	0.200	0.333
B 10	0.556	0.926	1.000	0.111	0.481	0.778	0.111	0.120	0.200

Step 4: Calculation of the fuzzy positive and negative ideal solutions: The fuzzy positive and negative ideal solutions are calculated based on each barrier's maximum and minimum degree of membership to each decision criterion, respectively. The fuzzy normalized weighted decision matrix is shown in **Table 11**.

Table 11. Fuzzy normalized weighted decision matrix.

Weights	7	9	9	5	7	9	3	5	7
	Sustainability			**Importance towards business**			**Cost-effectiveness**		
B 1	3.889	8.333	9	2.778	5.963	9.000	0.333	0.652	1.400
B 2	3.889	7.667	9	2.778	5.963	9.000	0.333	0.556	1.000
B 3	2.333	5.667	9	2.778	5.444	9.000	0.333	0.714	1.400
B 4	3.889	7.000	9	2.778	5.963	9.000	0.429	1.154	7.000
B 5	5.444	9.000	9	2.778	6.481	9.000	0.429	1.000	2.333
B 6	3.889	8.333	9	2.778	6.481	9.000	0.429	1.364	7.000
B 7	5.444	9.000	9	1.667	4.926	9.000	0.333	0.556	1.000
B 8	3.889	7.000	9	0.556	2.333	5.000	0.600	1.667	7.000
B 9	3.889	8.333	9	3.889	7.000	9.000	0.429	1.000	2.333
B 10	3.889	8.333	9	0.556	3.370	7.000	0.333	0.600	1.400
A*	**5.444**	**9.000**	**9.000**	**3.889**	**7.000**	**9.000**	**0.600**	**1.667**	**7.000**
A-	**2.333**	**5.667**	**9.000**	**0.556**	**2.333**	**5.000**	**0.333**	**0.556**	**1.000**

***Step 5: Calculation of the Separation Measures*:** Separation measures are computed to identify the distance between each barrier and the fuzzy positive and negative ideal solutions, as shown in **Table 12**.

Table 12. Separation from fuzzy positive and negative ideal solutions.

Barrier	Distance from FPIS			di*	Barrier	Distance from FNIS			di^-
B 1	0.977	0.877	3.289	5.144	B 1	1.782	3.372	0.238	5.392
B 2	1.183	0.877	3.526	5.587	B 2	1.463	3.372	0.000	4.835
B 3	2.632	1.104	3.283	7.019	B 3	0.000	3.195	0.248	3.443
B 4	1.463	0.877	0.312	2.653	B 4	1.183	3.372	3.482	8.037
B 5	0.000	0.708	2.723	3.431	B 5	2.632	3.566	0.813	7.012
B 6	0.977	0.708	0.201	1.886	B 6	1.782	3.566	3.496	8.844
B 7	0.000	1.755	3.526	5.281	B 7	2.632	2.826	0.000	5.458
B 8	1.463	4.037	0.000	5.500	B 8	1.183	0.000	3.526	4.709
B 9	0.977	0.000	1.924	2.901	B 9	1.782	4.037	0.813	6.633
B 10	0.977	3.071	3.295	7.343	B 10	1.782	1.301	0.232	3.315

***Step 6: Calculation of the Closeness Coefficient*:** The closeness coefficient is computed for each barrier by utilising its distance from the fuzzy positive and negative ideal solutions, as shown in **Table 13**.

Table 13. Closeness coefficient of barriers.

Barriers	CC_i	Ranking
B 1	0.51177	5
B 2	0.46393	7
B 3	0.32909	9
B 4	0.75184	2
B 5	0.67141	4
B 6	0.82423	1
B 7	0.50823	6
B 8	0.46128	8
B 9	0.69573	3
B 10	0.31107	10

***Step 7: Ranking of Barriers*:** The barriers are ranked based on their closeness coefficients, with the barriers with higher coefficients being ranked higher than those with lower coefficients, as shown in **Table 14**.

Table 14. Ranking of barriers.

Rank	Barriers	
1	B 6	Lack of an environmental partnership with buyers and suppliers
2	B 4	Design complexity when reusing or recycling old goods or products
3	B 9	Carbon emission, paint shop emissions etc.
4	B 5	Lack of environmental education and training professionals that lack the necessary skills
5	B 1	Less manpower available for greening supply chain
6	B 7	Long distance travelled
7	B 2	High green supply chain cost and greening cost
8	B 8	Absence of environmental policy for GSCM
9	B 3	Insufficient organizational resources to provide sufficient GSCM
10	B 10	More fuel consumption

4. Results

As explained in section 3, seventy-one barriers for GSCM in AEMI are explored from a literature view and expert input. The top ten barriers are selected by the Delphi method. Eighty-five experts are selected who are working in the AEMI. Questionnaires are developed by considering all these barriers. Experts are asked to rate a five-point scale (Likert scale) to each barrier in establishing GSCM in AEMI. Several significant barriers must be considered when implementing GSC in AEMI, as they impede their performance. The MCDM-Fuzzy TOPSIS methods determine the relative classification of the ten barriers. Regarding the impact of the ten barriers of the GSCM, three decision-makers provided feedback that was evaluated according to criteria like cost-effectiveness, sustainability and importance towards business.

The highest degree of closeness to the ideal solution indicates that a specific barrier influences the adoption of GSC practices in the AEMI. Therefore, the main top-rank barrier identified is the lack of an environmental partnership with buyers and suppliers, whereas the least significant barrier is more fuel consumption. The five significant barriers are the lack of an environmental partnership with buyers and suppliers, design complexity when reusing or recycling old goods or products, carbon emissions and emissions from paint shops, lack of environmental education and training professionals that lack the necessary skills and less human resources available for greening the supply chain.

5. Discussion on Results

The results regarding modeling barriers to GSCM in the AEMI using the fuzzy TOPSIS approach and blockchain- IoT integrated architecture are discussed. We applied the MCDM fuzzy TOPSIS approach to evaluate and rank the barriers to implementing GSCM in AEMI (Dandage et al., 2018; Kirkire et al., 2018). The findings discovered numerous significant barriers for the manufacturing industries to adopt sustainable practices.

Our studies emphasize that barriers like lack of an environmental partnership with buyers and suppliers are at the top rank, whereas more fuel consumption is at the lowest (Majumdar and Sinha, 2018; Malviya and Kant, 2018; Bai and Satir, 2020). Lack of an environmental partnership with buyers and suppliers, complexity of design to reuse products, carbon emission, paint shop emissions, lack of environmental education and training professionals that lack the necessary skills and less manpower available for greening supply chain are a few significant barriers (Govindan et al., 2014; Kaur et al., 2019; Tumpa et al., 2019).

As potential solutions to these barriers, we suggested blockchain IoT technologies. These technologies provide real-time monitoring, efficient data collection, secure record-keeping and transparent management practices (Baryannis et al., 2019; Nagariya et al., 2022). However, further study is required to establish how these technologies might be applied in the GSCM of agriculture equipment manufacturing. Future studies should concentrate on the functionality, cost, and potential difficulties of adopting such cutting-edge technologies into existing systems.

Overall, the discussion highlights the significance of addressing these barriers to completely fulfil the potential of GSCM in AEMI. To effectively mitigate these barriers, we developed IoT blockchain architecture and strategies. The AEMI could become more sustainable, transparent and efficient by adopting GSC.

5.1 Blockchain- IoT Integrated Architecture

Blockchain IoT-integrated architecture has the potential to address and mitigate the barriers to GSC in AEMI. IoT devices and networked machinery can track energy, waste, and resource use in production. This data can optimize the supply chain for efficiency and sustainability. This reduces waste and extends equipment life, saving the green supply chain cost (Baryannis et al., 2019; Pasi et al., 2020; Nagariya et al., 2022). Equipment health can be monitored by IoT sensors, allowing for the early detection of potential maintenance needs. It facilitates repairs, eliminates downtime, and optimizes resource use and manpower. By automation in energy management, AEMI can reduce their environmental effect (Muller and Voigt, 2018). Blockchain technology has the potential to provide end-to-end traceability and visibility across the GSC for all objects (Nagariya et al., 2022; Rane and Narvel, 2022). Stakeholders can verify the validity of sustainable practices and ensure compliance with green standards by documenting every transaction and movement on the blockchain, thereby eliminating the need for tedious manual audits (Kaur et al., 2018; Sajjad et al., 2020).

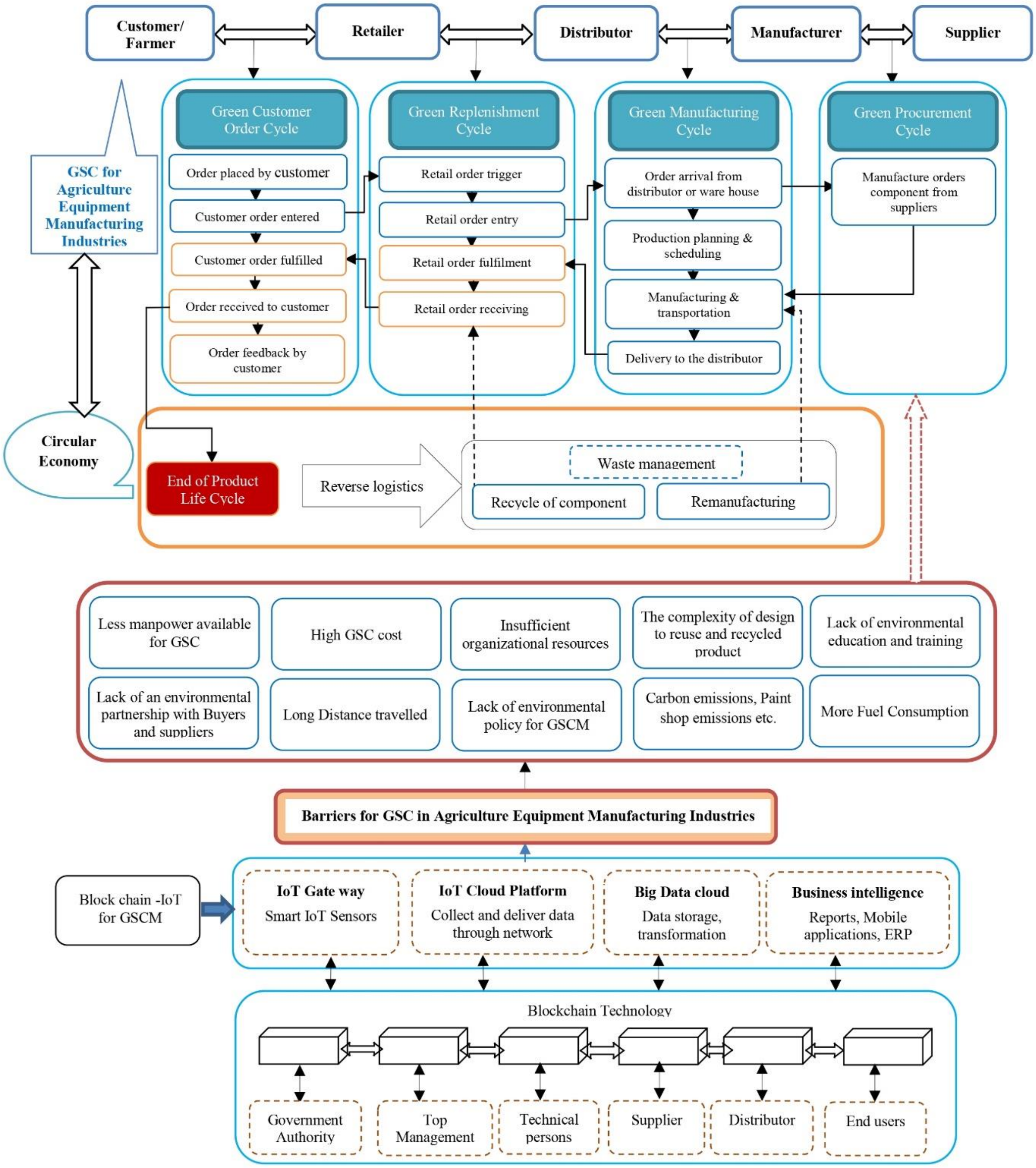

Figure 2. Blockchain- IoT integrated architecture for GSCM in AEMI.

The blockchain-IoT architecture for GSCM to AEMI is shown in **Figure 2**. IoT devices are placed at various points in the supply chain, such as manufacturing, transportation, and inventory storage. These devices collect temperature, humidity, location, and other relevant parameters and transmit them to the blockchain (Baryannis et al., 2019; Garrido-Hidalgo et al., 2019; Pasi et al., 2021; Nagariya et al., 2022). The blockchain network is responsible for storing and managing the data collected by IoT devices. The network can be a private or public blockchain, depending on the requirements of the supply chain. Smart contracts are deployed on the blockchain to automate various processes in the supply chain. These contracts can be used to enforce rules, such as the use of sustainable materials and ethical manufacturing practices (Saberi et al., 2019; Wang et al., 2019).

Data analytics tools are used to analyse the data gathered by IoT devices. This analysis may provide significant information about the supply chain, including the identification of bottlenecks and opportunities for improvement. Decentralized applications have the potential to be developed on the blockchain network, serving as a user interface for multiple stakeholders involved in the supply chain (Mao et al., 2019; Dwivedi et al., 2021). It can include manufacturers, suppliers, and consumers. Using an IoT blockchain architecture for GSCM, AEMI can ensure that their supply chain is sustainable, ethical, and transparent. It can improve efficiency, reduce costs, and increase customer trust (Luthra and Mangla, 2018; Manavalan and Jayakrishna, 2019; Pasi et al., 2020). The silent features of blockchain IoT architecture are as follows.

(i) IoT devices collect location, temperature, humidity, etc., data at multiple supply chain stages.
(ii) Blockchain stores and manages this data securely, ensuring it cannot be altered.
(iii) It can be a public or private blockchain, depending on the requirements of the supply chain.
(iv) Smart contracts automate processes and ensure compliance with sustainability regulations.
(v) Data analytics provides supply chain optimization with insights.
(vi) Decentralised applications provide a user interface for stakeholders.
(vii) It ensures a sustainable, transparent and ethical supply chain.
(viii) Improves operational efficiency and reduces costs, bolstering customer trust.

5.2 Blockchain IoT Based Strategies to Mitigate Barriers to GSC in AEMI

B1- Less Manpower Available for Greening Supply Chain

IoT sensors and networked machinery can monitor numerous aspects of the manufacturing process, such as energy consumption, waste management and resource utilization. The collection of real-time data facilitates proactive decision-making and reveals opportunities for improvement (Rane and Narvel, 2022). IoT-enabled sensors can monitor the health of equipment, allowing for the early detection of potential maintenance needs. It ensures prompt repairs, prevents downtime and optimizes resource utilization, eliminating the need for many personnel (Baryannis et al., 2019; Muller and Voigt, 2018; Rane et al., 2023a). By automating energy management, organizations can lessen their impact on the environment without depending solely on additional manpower. Blockchain technology has the potential to provide end-to-end traceability and visibility across the GSC for all objects. Stakeholders can verify the validity of sustainable practices and ensure compliance with green standards by documenting every transaction and movement on the blockchain, thereby eliminating the need for tedious manual audits (Abdel-Basset et al., 2018; Panghal et al., 2022).

B2- High Green Supply Chain Cost and Greening Cost

IoT devices can collect huge quantities of data regarding the supply chain, including energy consumption, waste generation, material usage and machine efficiency. This information can be utilized to optimize the supply chain, making it more efficient and environmentally friendly (Pasi et al., 2020; Rane et al., 2021b). This reduces waste and prolongs the equipment's useful life, reducing the green supply chain's expenses.

Combining IoT and blockchain can substantially reduce waste. IoT sensors can monitor and optimize the use of resources. In contrast, blockchain technology can track and optimize the lifecycle of products and materials, thereby encouraging CE practices such as recycling and reusing. This waste reduction can reduce the costs associated with the GSC and with greening (Baryannis et al., 2019; Pasi et al., 2021; Nagariya et al., 2022).

B3- Insufficient Organizational Resources to Provide Sufficient GSCM

By providing real-time data on each component of the supply chain, IoT enables operations to be optimized. Sensors can track everything from energy consumption to waste production, allowing organizations to identify inefficiencies and take corrective action. IoT devices can monitor the health of machinery and predict when it will require maintenance or replacement (Muller and Voigt, 2018; Rane et al., 2021). This preventive strategy can prevent costly failures and delays, saving resources for other GSCM components. Blockchain can reduce the need for intermediaries in the supply chain by providing an unchangeable, transparent ledger of transactions. This reduces costs and simplifies administration, providing GSCM with additional resources. Many compliance aspects can be automated using smart contracts based on the blockchain, eliminating the need for manual monitoring and enforcement (Saberi et al., 2019; Wang et al., 2019). This reduces the manpower and funds that could be used to enhance GSCM. Consequently, by leveraging IoT and blockchain, AEMI can more effectively allocate their limited resources, streamline and automate compliance, reduce waste, and enhance overall supply chain management, overcoming the barriers of insufficient organizational resources for GSCM (Mao et al., 2019; Panghal et al., 2022; Kafeel et al., 2023).

B4- Design Complexity when Reusing or Recycling Old Goods or Products

IoT devices can collect data on agricultural equipment, such as utilization patterns, maintenance records, and deterioration. This information can inform design improvements for product recycling and reuse. Design enhancements may concentrate on extending the service life of frequently worn parts or facilitating their replacement (Muller and Voigt, 2018; Rane and Narvel, 2022). When incorporated into product lifecycle management systems, IoT data can provide insights into product usage and end-of-life, guiding design towards recyclability or reuse. Blockchain technology can facilitate this process by preserving a transparent, unchanging ledger of equipment material compositions. This simplifies recycling and informs design for reuse by facilitating the identification of recyclable components at the product's end of life. The combination of IoT and blockchain facilitates the implementation of a CE (Baryannis et al., 2019; Mao et al., 2019; Prahathish et al., 2020). For instance, when a product ends, a smart contract activated by blockchain technology can notify manufacturers or recyclers. Furthermore, the blockchain can verify the authenticity and quality of recycled materials, boosting confidence in their application. This, in turn, promotes increased recycling throughout the supply chain (Wang et al., 2019; Prasad et al., 2022).

B5- Lack of Environmental Education and Training Professionals that Lack the Necessary Skills

In the manufacturing process, IoT devices can accumulate enormous quantities of data. This information can be used to develop realistic training scenarios for employees, enabling them to comprehend how their actions affect the environment (Baryannis et al., 2019; Garrido-Hidalgo et al., 2019; Pasi et al., 2021). For instance, they could discover how altering equipment settings or routine maintenance can reduce energy consumption and waste creation. IoT devices can provide environmental performance feedback in real-time (Muller and Voigt, 2018). This instantaneous information can serve as practical, ongoing training that teaches employees how to make sustainable decisions on the job. Integrating IoT and blockchain can generate an immense amount of data and information that can be used to create training modules, simulate real-world scenarios, and provide a deeper comprehension of the dynamics of GSC (Baryannis et al., 2019; Mao et al., 2019). It can aid in developing a curriculum that equips professionals with the necessary skills.

The blockchain's secure and decentralized nature can facilitate the development of online platforms for environmental education and training. These platforms could offer courses, certifications, and resources that are immutable and verifiable using blockchain technology (Wang et al., 2019; Prasad et al., 2022).

B6- Lack of an Environmental Partnership with Buyers and Suppliers

Blockchain can increase supply chain transparency, nurturing confidence between buyers and suppliers. Each transaction is recorded and cannot be altered, ensuring that all stakeholders have access to accurate, up-to-date data regarding the ecological effects of each supply chain link. Moreover, blockchain-based smart contracts can enforce supply chain environmental standards (Saberi et al., 2019; Wang et al., 2019). These digital contracts can initiate actions automatically when certain conditions are met. For instance, a smart contract could release payment to a supplier upon confirmation of their adherence to environmental standards. This facilitates compliance and promotes sustainable partnerships by requiring all parties to adhere to mutually agreed-upon standards. IoT gadgets can provide real-time environmental data, such as energy consumption, emissions, and waste (Rane et al., 2021b). This data can be shared with buyers and suppliers to demonstrate compliance with environmental standards and encourage partnerships based on shared sustainability objectives. Lastly, combining IoT and blockchain can create a shared platform for consumers and suppliers to monitor and achieve their sustainability goals. These technologies can facilitate cooperation and partnership in pursuing shared environmental objectives by providing a clear and accurate picture of environmental performance (Panghal et al., 2022; Kafeel et al., 2023).

B7- Long Distance Travelled

IoT devices can collect current data on traffic, weather and road conditions to optimize delivery routes, reduce unnecessary travel and reduce carbon emissions. The IoT sensors can monitor vehicle performance and efficiency, providing insights for preventive maintenance that guarantees vehicles operate at peak efficiency, thereby reducing their environmental impact (Muller and Voigt, 2018; Garrido-Hidalgo et al., 2019; Nagariya et al., 2022). In addition, IoT devices can monitor drivers' behaviour, encouraging fuel-saving driving techniques. By providing a transparent, real-time analysis of the entire supply chain, blockchain can help industries identify inefficiencies and duplications. For instance, it may reveal that products are being distributed overseas when a local source is feasible (Pasi et al., 2021). Integrating IoT and blockchain can provide precise traceability of products, components, and materials, enabling industries to make informed sourcing and distribution decisions that reduce travel distances and carbon emissions. AEMI can reduce supply chain travel distances and their environmental impact by employing IoT for efficient routing and maintenance and blockchain for transparency, traceability, and the possibility of decentralized manufacturing (Garrido-Hidalgo et al., 2019; Rane et al., 2023b).

B8- Absence of Environmental Policy for GSCM

IoT sensors can provide accurate, immediate data regarding the environmental impact of various supply chain stages. Policymakers can utilize this data to identify areas for improvement and formulate appropriate policies (Baryannis et al., 2019; Garrido-Hidalgo et al., 2019; Rane and Narvel, 2022). The capabilities of blockchain and smart contracts can automate policy enforcement. Smart contracts can be designed with policies that automatically monitor compliance and impose punishments for noncompliance (Saberi et al., 2019; Wang et al., 2019). Additionally, the data from IoT devices can be used to evaluate the efficacy of existing policies and facilitate any necessary adjustments. For example, if a policy seeks to reduce energy consumption, IoT data can determine whether this objective is being met (Pasi et al., 2021; Nagariya et al., 2022). The transparent and immutable ledger of blockchain provides a distinct record of policy implementation and results, nurturing stakeholders' trust and ensuring all parties' accountability in implementing environmental policies. The insights gleaned from the immense quantity of data collected by IoT devices and monitored via blockchain can inform the development of more effective and comprehensive environmental policies. In addition, blockchain technology can ensure alignment and conformance with global environmental standards and regulations, which is essential for multinational agriculture equipment manufacturers operating in diverse regulatory environments (Wang et al., 2019; Prasad et al., 2022).

B9- Carbon Emissions, Paint Shop Emissions, etc.

IoT devices can continuously monitor and collect emissions data in critical areas, such as exhaust systems and paint shops. Sensors can quantify the quantity and type of pollutants emitted. This real-time data can identify emission levels and their causes, allowing immediate corrective action. IoT devices can also assist with predictive equipment maintenance (Baryannis et al., 2019; Garrido-Hidalgo et al., 2019; Muller and Voigt, 2018). Organizations can avoid unnecessary emissions caused by inefficient machine operation or failures by identifying potential malfunctions prior to their occurrence. Moreover, IoT can optimize manufacturing energy consumption, thereby reducing carbon emissions. IoT devices can, for instance, monitor and manage energy consumption in factories, turn off equipment when it is not in use and modify settings for maximum energy efficiency (Pasi et al., 2020; Rane et al., 2021b). Furthermore, blockchain can provide a secure and transparent platform for monitoring carbon emissions throughout the supply chain. It could facilitate a carbon trading system in which industries that reduce emissions sell carbon credits to other organizations, promoting emission reductions and investment in greener technologies. Additionally, blockchain can track each stakeholder's sustainability practices in the supply chain, promoting sustainable manufacturing processes. It is possible to reward suppliers who employ low-emission practices, thereby generating a positive feedback cycle for emission reduction (Pasi et al., 2020; Prahathish et al., 2020; Nagariya et al., 2022).

B10- More Fuel Consumption

Various stages of the supply chain, such as transportation and equipment operation, can be monitored for real-time fuel uses by IoT sensors (Rane and Narvel, 2022; Garrido-Hidalgo et al., 2019; Pasi et al., 2021). These sensors can detect inefficient practices and equipment contributing to excessive fuel consumption. In addition, IoT can facilitate the predictive maintenance of vehicles and equipment, ensuring their optimal performance (Muller and Voigt, 2018). IoT can maintain optimal fuel efficiency by detecting potential issues before they cause equipment failure, reducing excessive fuel consumption. IoT devices can be utilized for real-time monitoring and route optimization in transportation logistics. By optimizing delivery routes, superfluous travel and fuel consumption can be reduced (Cavalcante et al., 2019; Kantasa-ard et al., 2019). In addition, blockchain can provide an integrated perspective of the supply chain, facilitating the identification of inefficiencies. It could reveal that goods are conveyed in smaller, more frequent quantities, resulting in excessive fuel consumption. With this knowledge, operations could be restructured to decrease total shipments and fuel consumption. Blockchain can also be used to enforce fuel efficiency standards using smart contracts (Saberi et al., 2019; Wang et al., 2019). Suppliers or logistics providers may be required to meet specific fuel efficiency standards to qualify for contracts, thereby encouraging investments in more fuel-efficient vehicles and equipment (Wang et al., 2019; Prasad et al., 2022).

6. Conclusion and Future Scope

In conclusion, this research paper focused on modeling the barriers to GSC for AEMI using the Fuzzy TOPSIS method and considering blockchain - IoT integrated architecture and strategies. The study addressed the significant barriers industries face in adopting sustainable methods and implementing eco-friendly supply chain processes. This study identified seventy-one barriers to establishing and successfully implementing a GSC in the AEMI through a comprehensive literature survey, expert inputs, and empirical analysis. These barriers are categorized into strategic, financial, organizational, technical, social-cultural, buyer and supplier, logistics, legislation, environmental and energy factors. Using the Fuzzy TOPSIS method, the study provided an exhaustive framework for evaluating and ranking these barriers, enabling decision-makers to allocate resources and develop effective strategies accordingly.

Moreover, integrating IoT and blockchain technologies into the proposed framework offered the potential to mitigate these barriers. Incorporating these cutting-edge technologies improves the supply chain's transparency, traceability and efficacy, thus promoting sustainable practices and reducing environmental impacts. In addition, integrating IoT and blockchain can facilitate real-time data sharing, automated transactions, and the implementation of smart contracts, resulting in enhanced cooperation, trust and collaboration among stakeholders. The findings of this study highlight the relevance of adopting an integrated approach to resolve the barriers of the GSC in industries that manufacture agricultural equipment's. It emphasizes the importance of collaborative efforts by all stakeholders, including manufacturers, policymakers, customers, suppliers and technologists. These industries can transition to more sustainable and environmentally favourable practices by integrating economic, technological, legal, organizational, and social factors. This study contributes to the existing body of knowledge by offering valuable insights into modeling the barriers of the GSC for AEMI. The proposed framework, which focuses on IoT-blockchain integration, provides a systematic approach to mitigating these barriers. The findings of this study can assist decision-makers in developing effective strategies and policies to promote sustainable practices and enhance the environmental performance of AEMI. The study effectively explores barriers to GSC. Still, the continuous shifts in the industry and environmental regulations could lead to the emergence of new barriers. Future research could investigate these challenges as the industry advances and regulations evolve. The proposed blockchain and IoT integrated architecture and strategies represent innovative solutions to overcome the identified barriers. However, the quick changeover of technological advances could provide even more efficient solutions. Further exploration of new technologies and their potential impact on GSC practices may strengthen AEMI's sustainability. The study integrates IoT and blockchain technologies to mitigate barriers to GSC practices. However, this approach may limit the applicability of the findings in environments where such technologies are either not available or feasible to implement due to cost, technical complexity, or lack of expertise

Incorporating GSC practices in the AEMI results in cost savings and efficiency gains and contributes to environmental protection. By reducing their environmental impact, these industries contribute to a greener economy and improve their standing among environmentally conscious customers. In order to attain a more sustainable and environmentally friendly supply chain, we must overcome barriers and implement sustainable practices.

Conflict of Interest

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

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