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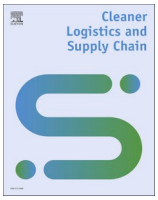

Industry 5.0 and green supply chain management synergy for sustainable development in Bangladeshi RMG industries

Md Al Amin [a,b,1,*], Arka Chakraborty [b,2], Roberto Baldacci [a,3]

[a] Division of Engineering Management and Decision Sciences, College of Science & Engineering, Hamad Bin Khalifa University, Doha 34110, Qatar
[b] Department of Industrial Engineering and Management, Khulna University of Engineering & Technology, Khulna 9203, Bangladesh

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ABSTRACT

The conjugation of environment and technology coerced the industry to combine these two instruments towards a sustainable and resilient future. Industry 5.0 is the most recent infrastructural revolution of industrial sector technology based on technologies like human–machine interaction, artificial intelligence, IoT, Big Data, collaborative robots, etc. This happened when the sector radically turned its global focus to sustainability and set many environmental goals to meet the requirements. In this research, the authors identified the synergy between Industry 5.0 and green supply chain management (GSCM) for achieving this target at RMG industries in Bangladesh. GSCM is well known for environmental concerns in traditional supply chain stages. For developing countries, the solution of a sustainable approach to counter waste and pollution-related issues is not adequate enough. A proper understanding of the digitalized industrial approach through Industry 5.0 will enable them to make efficient decisions regarding sustainable goal accomplishment and proper monitoring of the initiatives. This paper illustrates how I5.0 can integrate with GSCM. In this synergy, this study has identified 9 synergistic factors and analyzed the impact of each factor by using the interpretive structural modeling approach. By using level portioning, the factors are illustrated in 7 different levels, and MICMAC analysis is used to categorize them. This study offers a detailed exploration of the synergy between Industry 5.0 and GSCM, offering a practical framework that can guide industry stakeholders in implementing advanced technologies to achieve sustainable development in the RMG sector.

1. Introduction

The Industrial Revolution has continuously transformed workplaces to meet society's demands, with a growing emphasis on incorporating green practices due to environmental concerns (Sarkis et al., 2019; Micheli et al., 2020). This focus on sustainability is a defining feature of Industry 5.0, the latest chapter in industrial evolution. Industry 4.0, while still being adopted by some nations, laid the groundwork for this shift. It emphasized technological advancements like data analytics, forecasting, IoT, and blockchain to meet growing demands for supply flexibility and productivity (Yang et al., 2020; Xu et al., 2021). Industry 5.0 builds upon Industry 4.0′s technological foundation, but with a crucial shift: prioritizing sustainability and human well-being alongside efficiency (Breque et al., 2021). This human-centric approach acknowledges our planet's environmental challenges, emphasizing innovation for a long-term, sustainable future (Somohano-Rodríguez and Madrid-Guijarro, 2022). Green Supply Chain Management aligns perfectly with this vision. By integrating eco-friendly practices throughout the supply chain, GSCM minimizes environmental impact while promoting innovation for continued progress (Rauter et al., 2017; Geng et al., 2017). Technology plays a key role in achieving GSCM, with advancements acting as a crucial internal driver alongside strong organizational commitment (Chakraborty et al., 2023).

As the world approaches a critical threshold in global warming and strives to adhere to the Paris Agreement's goals, adopting more robust, scalable, and collaborative approaches that blend technology with GSCM is urgent (Matemilola et al., 2020). This research explores the promising synergy between I5.0 and GSCM, aiming to unlock their

* Corresponding author.
E-mail addresses: mdal44149@hbku.edu.qa (M.A. Amin), rbaldacci@hbku.edu.qa (R. Baldacci).
[1] 0000-0002-1712-3037.
[2] 0000-0002-6315-2277.
[3] 0000-0003-0938-5798.

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combined potential for sustainable development in Bangladesh's RMG industry. While I5.0 and GSCM can function independently, their true strength lies in their interrelation. I5.0 offers the tools to implement, measure, and optimize GSCM initiatives, creating a win–win for both environmental responsibility and operational efficiency. By providing resources, data-driven insights, and the ability to monitor environmental impact, I5.0 empowers GSCM to make supply chains eco-friendlier, paving the way for a sustainable future.

While GSCM addresses environmental concerns within traditional supply chains, developing countries like Bangladesh require a more comprehensive solution. A deeper understanding of Industry 5.0′s digitalized approach can empower these nations to make informed decisions to achieve sustainability goals and effectively monitor their initiatives (Al Amin and Baldacci, 2024). This study's approach appears to significantly contribute to analyzing industry 5.0 practices with a combination of GSCM practices. This research identifies nine key factors influencing this synergy and analyzes their impact using Interpretive Structural Modeling (ISM). Level portioning and MICMAC analysis further categorize these factors, providing a clear understanding of their relationships. Factors identified in this study are a combinational effort of industry experts from diversified RMG industries to pursue a pragmatic analysis about the subject across the industries.

The fundamental motivation for this research originates from the growing number of environmental issues, particularly the worsening of global warming caused by industrial operations (Karmaker et al., 2023a; Habib et al., 2022) and greenhouse gas emissions (Rupa and Saif, 2022; Sarkar et al., 2020) at RMG industries in Bangladesh. Global measures, such as trillions of dollars designated for mitigation strategies, demonstrate the global community's willingness to confront these environmental challenges. The research is motivated by the need to optimize and prioritize the allocation of these resources to achieve maximum effectiveness. This research aims to support a future in which RMG industries can effectively integrate Industry 5.0 technology into GSCM and support global sustainability objectives. In spite of having lots of initiatives from policy making to product category modification, overall progress in this sector is not satisfactory which is depicted in the report of the United Nations summit, where the world is well short to achieve net zero emissions by 2050 and other KPIs which were developed to make our attempts fruitful towards achieving sustainability (SDG Summit, 2023). This deficiency may result from many factors, and lack of proper combination with new age technology is one of them. This study proposes a framework for reimagining sustainable development within the context of Industry 5.0. The authors explore how we can significantly accelerate progress toward a sustainable future by strategically integrating Industry 5.0 tools into everyday supply service operations. GSCM practice and it's policy making is a global phenomenon. Global summits like COP 26 and COP 27 are establishing goals for RMG industries to reduce their negative environmental impact through tactics like achieving carbon positivity, decarbonization, water neutrality, waste margin limits, etc. and enforcing legal sanctions like carbon taxes on those who won't be able to comply. Technological strategies and green approaches to collaboration can be a major panacea for that. But implementing all the initiatives in a single stage will be a naive point from the strategic landscape. This research helps to identify the priority-based ranking of the factors for the successful achievement of sustainable development goals in GSCM field with the help of I5.0. This study conducts ISM approach to transform the subjective point of view of subject matter experts in an objective manner. The study has attempted to answer the following research questions:

RQ1: What is the synergy between Industry 5.0 and green supply chain management?

RQ2: How does the synergy between Industry 5.0 and green supply chain management contribute to achieving sustainable development?

To the best of our knowledge, no substantial research has been carried out on meeting efficiency and sustainability goals using I5.0 and GSCM methodologies in the current highly competitive and sustainability-focused global business environment. The various government and industry organizations are trying to establish a useful framework for developing policies for I5.0, GSCM, and sustainable development. This research proposed a framework for worldwide initiatives by governments, businesses, and community organizations to address the factors driving I5.0 and GSCM for sustainable goals. This research finds the relationship between Industry 5.0 and GSCM and their effects on sustainable development. The roadmap to Industry 5.0-driven sustainability that was produced in this study is expected to provide a deeper understanding of how GSCM and Industry 5.0 may contribute to sustainable development goals at RMG industries in Bangladesh.

The literature review on the synergy and synergistic factors is presented in section 2. Section 3 elaborates on the research methodology, while section 4 discusses the research findings. Section 5 outlines the implementation roadmap, and section 6 highlights the research's contributions to the Sustainable Development Goals. Finally, section 7 concludes by summarizing the key findings, proposing managerial implications and outlining the future scope of the research.

2. Literature review

This section highlights previous research on I5.0, GSCM and Sustainable developments. However, to summarize the previous works, we divided them into the following separate categories: (i) Definition and significance of I5.0, GSCM and Sustainable developments (ii) Synergy between I5.0 and GSCM towards achieving sustainable developments (iii) Similar studies, research gap and Motivations. The theoretical basis for the synergy and integration of I5.0 and GSCM in advancing sustainable development is discussed in sections 2.1–2.3. The following description covers these categories systematically.

2.1. Industry 5.0, GSCM and sustainable developments

Green Supply Chain Management is of particular significance to the RMG industry in Bangladesh. Here, GSCM becomes a strategic approach within supply chains to mitigate environmental risks that are often substantial in garment production. It encompasses a range of environmental practices integrated into production, sourcing, and logistics, with the aim of embedding environmental considerations throughout these processes (Zeng et al., 2022). These practices include reducing fabric waste during cutting, adopting eco-friendly dyes and washing processes, selecting suppliers based on their environmental performance, and minimizing carbon emissions during transportation of garments (Le, 2023; Whitelock, 2015). GSCM in Bangladeshi RMG sector extends beyond a company's internal operations, involving the management of suppliers and incorporating elements such as environmental certifications, government regulations, sustainable design, and eco-friendly packaging (Morgan and Liker, 2020; Vinodh and Rathod, 2014; Dahmani et al., 2021). A key component of GSCM is the management of the entire supply chain lifecycle, from suppliers through production to customers and even reverse logistics (Romli et al, 2015).

Industry 5.0, on the other hand, defines a collaborative industrial environment where humans and smart machines, including robots, synergize to enhance productivity, efficiency, and reduce waste (Selvaraj et al., 2009). This approach integrates the strengths of human ingenuity and machine capabilities, offering high precision due to human control and optimum automation for efficiency. It is driven by the objective to meet customers' specific and individualized requirements by combining the creativity of humans with the capabilities of machines (Ford and Despeisse, 2016). Industry 5.0 represents a dynamic, resilient, and human-centric concept of industrial development where intelligent digital ecosystems, enriched by human interaction, streamline workflows and enhance user experiences (Zafar et al., 2024). However, Sustainable development is a multidisciplinary concept that harmonizes environmental, economic, and social impacts within decision-making and actions. It revolves around addressing societal

issues in an eco-friendly and economically viable manner while ensuring our activities meet current needs without compromising the ability of future generations to meet their needs (Debnath et al., 2023).

In the context of the United Nations' 17 Sustainable Development Goals (SDGs), sustainable development in the Bangladeshi RMG industry should be framed around environmental responsibility, economic growth, and improving the social well-being of garment workers (Akter et al., 2022; Bristi et al., 2020). GSCM is a crucial element within the broader context of Environmental, Social, and Governance (ESG) and Corporate Social Responsibility (CSR) strategies for Bangladeshi RMG industry (Oberle et al., 2019). While GSCM primarily focuses on minimizing the environmental impact within the supply chain, it complements and enriches these sustainability frameworks. GSCM focuses on the environmental sustainability of manufacturing and distribution processes, making it an essential component of ESG's environmental dimension. Additionally, considering the significant environmental impact of Bangladesh's RMG supply chain, tackling these issues is a crucial part of the industry's ESG and CSR responsibilities. Moreover, GSCM indirectly influences social and governance aspects by promoting responsible sourcing of materials, safe working conditions, and ethical practices throughout the supply chain, aligning with the broader social and governance pillars of ESG and CSR (Zeng et al., 2022; Le, 2023; Whitelock, 2015).

2.2. Synergy between I5.0 and GSCM

The synergy between I5.0 and GSCM can revolutionize how businesses operate in an environmentally conscious world. I5.0 enables businesses to enhance their supply chain and production operations thanks to cutting-edge technology like IoT, AI, and data analytics. When integrated with GSCM principles, this synergy can yield significant environmental benefits. Real-time monitoring of resource utilization, energy consumption, and waste generation can lead to data-driven decisions that reduce waste and enhance resource efficiency, aligning with the core objectives of GSCM. Furthermore, I5.0 helps achieve environmental sustainability by lowering energy consumption and emissions by optimizing production and distribution operations. Transparency and traceability, inherent in I5.0, aid in tracking the environmental footprint of products and materials, while collaborative efforts among supply chain stakeholders can be extended to eco-friendly initiatives. In this synergy, businesses enhance their environmental stewardship and improve their operational efficiency and competitiveness, aligning profit with planet-conscious principles. Researchers explored how I5.0 and GSCM work together in the Bangladeshi RMG industry. The authors have identified nine crucial factors through literature reviews and consultations with industry professionals, academics, and supply chain/technology experts. To gain deeper insights, they conducted a focused group discussion with 18 experts, who evaluated the presence of these factors across four key areas: management, information flow, integration, and production. The synergistic factors are displayed in Table 1.

Table 1
Synergistic factors between I5.0 and GSCM.

Sl. No.	Factor Name	References
1	Green Designing	(Morgan and Liker, 2020; Vinodh and Rathod, 2014; Dahmani et al., 2021; Romli et al, 2015; Selvaraj et al., 2009; Zafar et al., 2024)
2	Real-time Data Visibility	(Romli et al, 2015; Selvaraj et al., 2009; Ford and Despeisse, 2016; Zafar et al., 2024; Debnath et al., 2023; Akter et al., 2022)
3	Effective Life Cycle Analysis	(Oberle et al., 2019; Hauschild et al., 2018; UNEP annual report, 2011; Simonen, 2014; Ferdous et al., 2023)
4	Green Logistics System	(Nowakowska-Grunt, 2008; Yousefi and Tosarkani, 2022)
5	Smart Manufacturing	(Wang et al., 2016; Meng et al., 2018; Shrouf et al., 2014)
6	Smart Grid and Metering	(Paul et al., 2014; Yu et al., 2015)
7	Man-Machine Interaction	(Kaasinen et al., 2022; Burns and Hajdukiewicz, 2017; Lu et al., 2022)
8	Green Human Resource Management	(Zaid et al., 2018; Gholami et al., 2016; Trujillo-Gallego et al., 2022; Jabbour and de Sousa Jabbour, 2016; Yu et al., 2020)
9	Circular Economy	(Bjørn et al., 2016; Han et al., 2020; Pagoropoulos et al., 2017; Maiurova et al., 2022; Govindan et al., 2015)

The journey towards sustainability in product development initiates a fundamental shift towards *Green Design* systems that promote reusability, recyclability, and prolonged product lifespan, effectively reducing ecological footprints. Sustainability efforts begin at the planning stage, considering cost, development time, and resource allocation, while the adoption of circular business models focusing on waste reduction and operational efficiency places eco-design concepts at the forefront (Morgan and Liker, 2020; Vinodh and Rathod, 2014; Dahmani et al., 2021). These concepts entail reduced material usage, increased productivity, and cost savings through design enhancements, including techniques like "Design to Cost." The infusion of technology into the design process is pivotal for realizing sustainable objectives, streamlining operations, and reducing raw material consumption, with additive manufacturing technology playing a key role in minimizing material wastage (Romli et al, 2015; Selvaraj et al., 2009; Zafar et al., 2024). In the realm of GSCM, enhancing *Real-time Data Visibility* through digitalization is essential to mitigate supply chain risks, and Industry 5.0 introduces transformative technologies like the Industrial Internet of Things (IIoT), Radio Frequency Identification (RFID), and Blockchain Technology, thereby positively impacting supply chain sustainability (Zafar et al., 2024; Debnath et al., 2023; Akter et al., 2022). Sustainable development is closely linked to global consumption patterns, necessitating tools like *Lifecycle Assessment (LCA)* and Life Cycle Sustainability Assessment (LCSA) to analyze environmental, social, and economic impacts and benefits throughout a product's lifecycle (Oberle et al., 2019; Hauschild et al., 2018; UNEP annual report, 2011). In the context of Industry 5.0, simulation-based approaches, which integrate simulation, optimization-based LCA, and Techno Economic Analysis (TEA), are used to comprehensively assess sustainability within the supply chain (Simonen, 2014; Ferdous et al., 2023).

Logistics systems encompass various elements like freight transport, material handling, packaging, warehousing, and both forward and reverse product flows, play a central role in the supply chain (Nowakowska-Grunt, 2008). A *Green Logistics System* adopts a holistic, interdisciplinary approach, aligning ecological, social, and financial considerations to enhance environmental efficiency in the management of product and material flows. Industry 5.0 introduces technology-based solutions like IoT-based maintenance systems to mitigate logistics risks by reducing machine breakdowns through data analysis, optimizing maintenance schedules, and averting supply delays (Yousefi and Tosarkani, 2022). *Smart Manufacturing* leverages computational techniques to analyze manufacturing processes based on data, enabling data-driven decisions to enhance efficiency and contribute to sustainable development (Wang et al., 2016). This approach is characterized by three crucial aspects: vertical, horizontal, and end-to-end integration, which collectively optimize resource utilization and make the manufacturing process flexible, faster, automated, and eco-friendly (Meng et al., 2018; Shrouf et al., 2014). Sustainability faces key environmental challenges, primarily caused by industrial output, with greenhouse gas (GHG) emissions serving as a vital metric for sustainable development. *Smart Grid Metering* technology plays a crucial role by measuring energy consumption, monitoring emissions, and guiding the transition to sustainable energy sources (Paul et al., 2014). Smart metering technology enhances energy efficiency, predicts power shortages, and self-heals through AI integration, significantly reducing power shutdowns (Yu et al., 2015). If left unaddressed, these power shutdowns disrupt manufacturing processes, create waste, and contribute to machine breakdowns, all of which pose substantial sustainability

challenges.

Industry 5.0 brings in a new era of manufacturing by stressing *Man-Machine Interaction*, distinguishing itself from Industry 4.0. The joint collaborative system (JCS) blends automation and human intervention to enable innovative problem-solving and informed decision-making (Kaasinen et al., 2022). Design complexity is managed through ecological interface design (EID), ensuring the optimized utilization of resources (Burns and Hajdukiewicz, 2017). The key highlight of man–machine interaction in Industry 5.0 is optimized resource utilization (Lu et al., 2022). The sustainability journey is not confined to technological and manufacturing aspects; it extends to human resource development, where *Green Human Resource Management (GHRM)* plays a pivotal role (Zaid et al., 2018; Gholami et al., 2016). Leveraging digital technologies such as big data analysis, IoT, cloud computing, and digital platforms, GHRM aligns human resource development with sustainability objectives and instills environmental consciousness within organizations (Trujillo-Gallego et al., 2022). The function of GSCM is pivotal in taking advantage of digital technological architecture and green human resource management for performance enhancement (Jabbour and de Sousa Jabbour, 2016). GHRM practice with digital technologies is necessary for cultural change in companies (Yu et al., 2020). Furthermore, transitioning from a linear to a circular economy is paramount for sustainability. The *Circular Economy* emphasizes resource maximization by promoting product reuse, remanufacturing, and recycling, thus mitigating resource scarcity and waste. Under Industry 5.0, digital technologies like RFID, blockchain, IoT, big data, and AI enhance the circular economy's efficiency and effectiveness (Bjørn et al., 2016; Han et al., 2020; Pagoropoulos et al., 2017; Maiurova et al., 2022; Govindan et al., 2015).

2.3. Similar literatures & research gap

Industry 5.0 and Green Supply Chain Management concepts are emerging areas of research with significant potential for achieving sustainable development. Several studies have been conducted in the fields of I5.0 and GSCM, each offering valuable insights while revealing notable research gaps:

- One study explored the interaction between Industry 5.0 and circular supply chains for sustainable development, identifying 16 factors through expert opinions and using the T-ISM approach, but it focused only on Industry 5.0 factors, leaving mainstream supply line factors unanalyzed (Dwivedi et al., 2023).
- Another study assessed the impact of Industry 4.0 technologies on waste management within circular supply chains, but it failed to address Industry 5.0 advancements or the potential for process and capacity development (Mastos et al., 2021).
- Additionally, a study mapped the transition from Industry 4.0 to Industry 5.0, highlighting sustainability issues in Industry 4.0, yet it did not provide a detailed factor-based analysis or consider the supply chain's role (Grabowska et al., 2022).
- Other research successfully portrayed Industry 5.0 technologies and their industrial development impacts but lacked analysis on sustainable development (Adel, 2022).
- One notable study used the ISM approach to assess Industry 5.0′s impact on post-pandemic supply chain sustainability, but a holistic view of GSCM was not included (Karmaker et al., 2023b).
- Further research examined modern technologies' influence on GSCM using a survey-based approach for reliability analysis and hypothesis testing, although it did not explore the interaction between Industry 5.0 and GSCM (Seman et al., 2019).
- Another study tested the impact of Industry 4.0 on lean manufacturing and sustainability, but did not analyze cross-functional relationships among factors (Varela et al., 2019).
- Similarly, researchers established a link between Industry 4.0, GSCM, operational performance, and environmental efficiency using a 7-point Likert scale but did not identify specific factors (Sunmola and Javahernia, 2021).
- A bibliometric study explored how digital technologies affect the circular economy during the transition from Industry 4.0 to 5.0 but lacked analysis of Industry 5.0 and GSCM integration (Atif, 2023).
- Additionally, studies on biofuel industries identified barriers to sustainable supply chains, but further research is needed to develop strategies to overcome these barriers (Narwane et al., 2021).
- Finally, studies using ISM and T-ISM approaches identified crucial factors for GSCM, yet did not delve into how digital technologies, particularly those of Industry 5.0, could enhance GSCM practices (Lim et al., 2017; (Shibin et al., 2017).

The literature reveals that the practice of Industry 5.0 is still emerging, with researchers actively exploring ways to integrate it into existing industrial operations. Industry 5.0 has not yet been widely implemented in developing countries, and its potential for growth requires clear knowledge and structured guidelines. Unlike the previous fourth industrial revolution, Industry 5.0 offers distinct opportunities for achieving sustainability. At the same time, green supply chain management is gaining heightened attention due to the urgent need to address climate change. Previous studies have largely focused on motivations, challenges, and strategies in the context of Industry 4.0, GSCM, and Industry 5.0. However, despite the significant potential of Industry 5.0 for advancing GSCM, research on the integration of these two fields remains limited. Few studies have examined the synergistic adoption of Industry 5.0 and GSCM. To address this gap, the current research will investigate and highlight the key relationships between the factors of Industry 5.0 and GSCM, offering new insights into their combined potential for sustainable development.

3. Methodology

The research methodology is composed of three main components. First, comprehensive information from the literature is reviewed and summarized, with consultations from subject matter experts to finalize the list of synergistic factors. The second component involves analyzing the reliability and consistency of the collected data, ensuring its validity for further analysis. Lastly, the third component involves applying the Interpretive Structural Modeling technique to determine the interrelationships among synergistic factors and to analyze their relative importance within a structured model.

3.1. Data collection

This research focuses on the RMG industries in Dhaka, Bangladesh, specifically exploring the synergy between GSCM and I5.0. Based on an extensive literature review and expert evaluations, nine key factors contributing to this synergy were identified. Table 1 summarizes the literature reviews for each synergistic factor. A focused group discussion was conducted with 18 subject matter experts, each with no less than seven years of experience in their respective fields. A total of 23 participants were invited, out of which 18 responded, representing a balance of both academic and industry professionals. The average data from these 18 experts were used for the analysis to ensure a comprehensive perspective from both academia and industry. During the focused group discussion, experts were asked to evaluate the nine identified synergistic factors. The discussion was iterative, with experts reviewing, debating, and reaching a consensus on the relevance and applicability of these factors to the Bangladeshi RMG sector. After confirming that these factors were suitable for the context of the RMG industry, a set of questionnaires related to these factors was distributed. Experts were then asked to rate the factors using a 5-point Likert scale. The ratings were gathered during the same session, and this data formed the foundation for subsequent analysis.

3.2. Reliability and consistency analysis

To validate the reliability and consistency of the data collected from the expert group, statistical analysis was conducted using SPSS 23. The Cronbach's alpha value (α = 0.879) was calculated, indicating that the data is highly reliable. Table 2 provides the detailed results of this reliability analysis.

In addition to checking reliability, the consistency of the data was analyzed across five key perspectives: managerial (P1), information (P2), integration (P3), production (P4) and environmental (P5). The inclusion of the environmental perspective was critical to ensure that sustainability aspects were thoroughly addressed in the supply chain management context. The consistency analysis was performed using Kappa Statistics, which yielded a value of K = 0.215. This value falls within the range of 0.21–0.40, indicating a fair degree of consistency among the respondents' answers. Table 3 shows the detailed results. In this context, Pi denotes the level of expert involvement for the ith synergy, while Pj refers to the percentage of assignments within the jth category. Although the consistency level is moderate, it is sufficient to justify further analysis and supports the validity of the data. Additionally, member checking will be applied to validate the findings once the final model is generated. This approach is widely used in qualitative research to enhance the validity and credibility of research work (Sahakyan, 2023).

3.3. Proposed method

For this research, ISM was employed as the research method to analyze the identified synergistic factors. ISM can systematically use conceptual, judgmental, and computational resources to provide an in-depth understanding of the pattern of the contextual relation among complex system elements. ISM allows the interpretation of the contextual relationships among each pair of elements. It can use qualitative data collection methods like in-depth interviews or group decision-making techniques to capture the experts' collective opinions and knowledge base. ISM can also be used in conjunction with interpretive logic-based knowledge to interpret the functionality of each pair of relationships (Soni et al., 2020). Using expert judgments, ISM enables researchers to build visual representations of poorly understood complicated systems. The current research is exploratory because Industry 5.0 is still in its infancy and has received little prior attention. The functions of Industry 5.0 for sustainable development are therefore explored using ISM and organized into a thorough interpretive model. This widely recognized computer-based method is used to examine the relationships between different factors and produce a graphical representation of the system. It is particularly effective for understanding the complexities of real-world scenarios when compared to other analytical tools like AHP and ANP (Jayant et al., 2015).

Table 2
Reliability and item statistics.

Reliability Statistics			
No. of respondents = 18	Cronbach's Alpha (α) = 0.879		
Item Statistics			
Synergistic Factors	Mean	Std. Deviation	Corrected Item-Total Correlation
A	4.6667	0.48507	0.571
B	4.6111	0.50163	0.385
C	4.5556	0.51131	0.539
D	4.6111	0.50163	0.314
E	4.3333	0.97014	0.600
F	4.3889	0.50163	0.787
G	4.5000	0.51450	0.905
H	4.5000	0.51450	0.905
I	4.5000	0.51450	0.905

Table 3
18 experts from 5 perspectives.

Synergistic Factors	**Perspectives**					**Pi**
	P1	**P2**	**P3**	**P4**	**P5**	
A	0	0	0	3	15	0.47056
B	0	15	3	0	0	0.47056
C	0	13	5	0	0	0.33987
D	5	0	0	0	13	0.33987
E	0	0	3	15	0	0.47059
F	5	0	0	13	0	0.33987
G	0	0	5	13	0	0.33987
H	14	0	0	0	4	0.39869
I	5	0	0	0	13	0.33986
Pj	0.179	0.173	0.099	0.272	0.278	K = 0.215

Unlike other analytical methods, ISM establishes interrelationships between factors and prioritizes them based on their level of importance. In place of deriving qualitative relations, ISM approach combines the observation of subject matter experts from that field. With the pragmatic observation from the experts, a new solution is coined as the consensus of focus group study. Other methods like AHP and ANP can be fruitful for data centric model where individual observations are priority. ISM was chosen over AHP and ANP in our study because of its qualitative, relationship-oriented approach. ISM excels in analyzing complex, real-world situations with intricate, non-linear interconnections among factors (Shaikh et al., 2024). Compared to fuzzy ISM and Total Interpretive Structural Modeling (TISM), the ISM method was selected due to its balance between clarity and complexity. While fuzzy ISM improves accuracy by accounting for uncertainty and ambiguity in expert opinions, ISM offers the clarity needed to establish a hierarchical structure of synergies without adding unnecessary complexity (Jain and Raj, 2021). Additionally, although TISM enhances the interpretive process, it tends to introduce more subjectivity (Dwivedi et al., 2023). In terms of prioritizing individual approaches, some factors that are special for a particular situation may be overlooked but may be obsolete for another area. In order to develop a general guideline that can be effectively considered as a ubiquitous guideline, the ISM approach will enable to reach that consensus. In the ISM approach, subject matter experts of related fields first evaluate each other's perspective and finally reach a consensus with proper validation and approval from all the members. In this research using the ISM approach, authors have successfully enumerated the framework of sustainable supply chain which can be attained by using several factors of industry 5.0 in a logical sequence. The survey responders for the ISM approach is recommended to be between 10–30 to ensure unity in response and reduce the biasness (Sayrs, 1998).

In Fig. 1, the research protocol for this methodology is illustrated. There are following stages in this ISM approach:

Step 1: From several literature reviews, mentioned in the Table 1, subject matter experts have selected 9 synergistic factors for the study where the synergy of industry 5.0 and GSCM has been analyzed.

Step 2: Based on focused group discussion, subject matter experts have developed contextual relationships based on which factors have been analyzed. A total 36 contextual relation have been analyzed in the study. Based on these 36 relations, 45 other relations were discovered. In total 81 relation have been discovered among the interaction of 9 synergistic factors.

Step 3: Structural self-interaction matrix (SSIM) is created to show how the different factors within a system are related to each other in pairs. SSIM matrix indicates pairwise relationship among the factors. There are 4 possible pair-wise relation can be measured. V, A, X, O.

(1) V: Criterion i will lead to criterion j.
(2) A: Criterion j will lead to criterion i.
(3) X: Criterion i and j will lead to each other.
(4) O: Criterion i and j are unrelated.

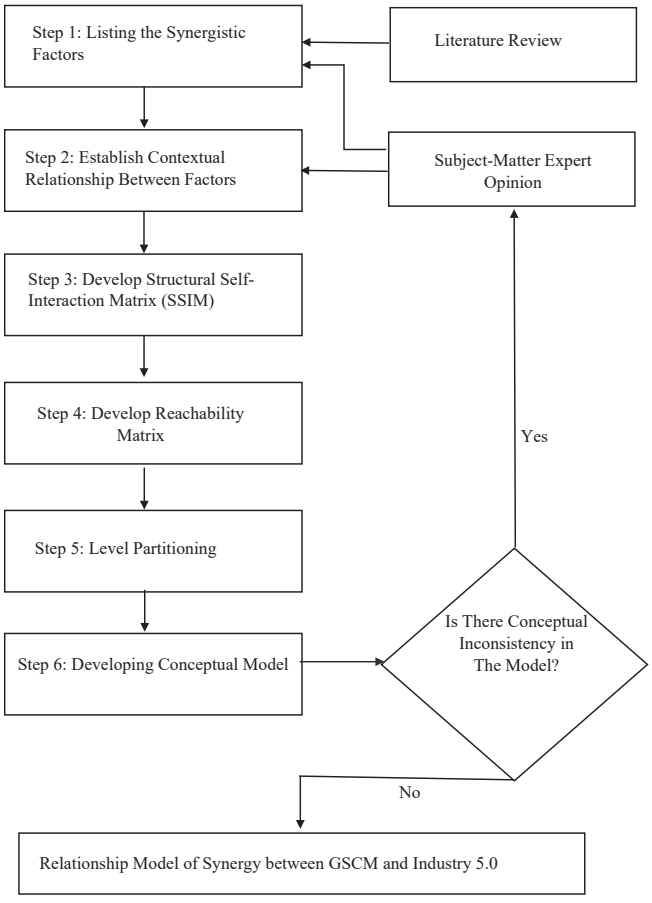

Fig. 1. Research Protocol.

Based on the pairwise comparison, SSIM matrix has been developed in Table 4.

Step 4: The SSIM is used to create a Reachability matrix, which is then used to develop a "final reachability matrix." In the ISM, contextual relationships are assumed to be transitive, meaning that if A is related to B and B is related to C, then A must be related to C. The Reachability matrix is developed here using Microsoft Excel 2016.

Reachability matrix uses binary values to convert the values of SSIM matrix into countable values. The value conversion is performed in four possible ways:

- When relation of pair (i, j) in SSIM is V, the value of (i, j) in reachability matrix is 1 and the value of (j, i) is 0.
- When the relation of pair (i, j) in SSIM is A, the value of (i, j) in reachability matrix is 0 and the value of (j, i) is 1.
- When the relation of pair (i, j) in SSIM is X, the value of (i, j) in reachability matrix is 1 and the value of (j, i) is 1.
- When relation of pair (i, j) in SSIM is O, the value of (i, j) in reachability matrix is 0 and the value of (j, i) is also 0.

The final reachability matrix is obtained from the initial reachability matrix. In this process, the total of the values in each column indicates the dependence power of the corresponding factor, while the total of the values in each row reflects its driving power. Table 5 presents the final reachability matrix. Driving power reflects a factor's ability to influence or impact other factors in achieving sustainability, with higher driving power indicating a more critical role in sustainable development. Dependence power, on the other hand, measures how much a factor relies on other factors. These two terms are inversely related: a factor with the highest driving power has the lowest dependence power.

Step 5: The factors are portioned in different levels based on their reachability set in this stage.

From the SSIM, the reachability and antecedent sets for each synergistic factor are identified. The reachability set consists of the factor itself and the factors it helps to achieve, while the antecedent set includes the factors that contribute to its achievement, along with the factor itself. The intersection of these two sets forms the interaction set. The level of each factor is determined based on its reachability set. Factors with the largest reachability sets are placed at the base level, while those with the smallest reachability sets are positioned at the topmost level. Factors at the same level share equal reachability sets. The level partition is illustrated in Table 6.

4. Result and discussion

In this study, authors have used the ISM approach to analyze the impact of GSCM and Industry 5.0 towards sustainable development. From the reachability matrix and level portioning process, this study identified the 9 synergistic factors distributed in 7 different levels based on their driving power.

Table 4
SSIM Matrix.

		Factor j								
SL No.	Factor i	Green Designing	Real-Time Data Visibility	Effective life cycle analysis	Green Logistics System	Smart Manufacturing	Smart Grid & Metering	Man-Machine Interaction	Green Human Resource Management	Circular Economy
A	Green Designing	X	V	V	V	V	V	V	V	V
B	Real-Time Data Visibility	A	X	X	V	A	V	A	V	V
C	Effective life cycle analysis	A	X	X	V	A	V	A	V	V
D	Green Logistics System	A	A	A	X	A	A	A	A	A
E	Smart Manufacturing	A	V	V	V	X	V	X	V	V
F	Smart Grid & Metering	A	A	A	V	A	X	A	V	V
G	Man-Machine Interaction	A	V	V	V	X	V	X	V	V
H	Green Human Resource Management	A	A	A	V	A	A	A	X	A
I	Circular Economy	A	A	A	V	A	A	A	V	X

Table 5
Final Reachability Matrix.

SL No.		Green Designing	Real-Time Data Visibility	Effective life cycle analysis	Green Logistics System	Smart Manufacturing	Smart Grid & Metering	Man-Machine Interaction	Green Human Resource Management	Circular Economy	Driving Power
A	Green Designing	1	1	1	1	1	1	1	1	1	9
E	Smart Manufacturing	0	1	1	1	1	1	1	1	1	8
G	Man-Machine Interaction	0	1	1	1	1	1	1	1	1	8
B	Real-Time Data Visibility	0	1	1	1	0	1	0	1	1	6
C	Effective life cycle analysis	0	1	1	1	0	0	0	1	1	6
F	Smart Grid & Metering	0	0	1	1	0	1	0	1	1	4
I	Circular Economy	0	0	0	1	0	0	0	1	1	3
H	Green Human Resource Management	0	0	0	1	0	0	0	1	0	2
D	Green Logistics System	0	0	0	1	0	0	0	0	0	1
	Dependence Power	2	5	6	9	3	5	3	8	7	

Table 6
Level Partition.

Factor No.	Factor Name	Reachability Set	Antecedent Set	Interaction Set	Level
A	Green Designing	A, B, C, D, E, F, G, H, I	A	A	Level VII
B	Real-Time Data Visibility	B, C, D, F, H, I	A, B, C, E, G	B, C	Level V
C	Effective life cycle analysis	B, C, D, F, H, I	A, B, C, E, F, G	B, C	Level V
D	Green Logistics System	D	A, B, C, D, E, F, G, H, I	D	Level I
E	Smart Manufacturing	B, C, D, E, F, G, H, I	A, E	E	Level VI
F	Smart Grid & Metering	C, D, F, H, I	A, B, E, F, G	F	Level IV
G	Man-Machine Interaction	B, D, E, F, G, H, I	A, G	G	Level VI
H	Green Human Resource Management	D,H	A, B, C, E, F, G, H, I	H	Level II
I	Circular Economy	D, H, I	A, B, C, E, F, G, I	I	Level III

4.1. ISM based model

In Fig. 2, the conceptual model illustrates the relationships among the nine synergistic factors, highlighting their correlations based on driving power and level partitioning. Green design is positioned at Level VII, indicating that it is the most critical factor for ensuring the sustainable practice of GSCM. Therefore, the initial stage of implementation will prioritize Industry 5.0 technologies that support and enhance the green design process. In addressing the critical role of green design within GSCM and its effective implementation in the context of Industry 5.0, this study emphasizes the significance of integrating sustainable design principles throughout the product lifecycle. Green design focuses on creating environmentally friendly products by minimizing waste and utilizing sustainable materials, which directly aligns with GSCM objectives. To support this integration, Industry 5.0 technologies, such as Artificial Intelligence (AI) and the Internet of Things (IoT), facilitate real-time data monitoring and optimization of resource allocation, enhancing the efficacy of green design strategies. Level VI comprises two interrelated factors: man–machine interaction and smart manufacturing. Both factors depend on green design and mutually influence each other. Man-machine interaction is a prerequisite for smart manufacturing, which relies on technologies such as collaborative robots and human-controlled devices. This interdependence underscores the equal importance of both factors in the implementation process. Moving to Level V, effective life cycle analysis and real-time data visibility drive each other in a reciprocal manner. Real-time data visibility offers insights into the ongoing lifecycle of a product, while life cycle analysis serves as a critical parameter for performing, comparing, and generating reports based on real-time data. Both factors significantly

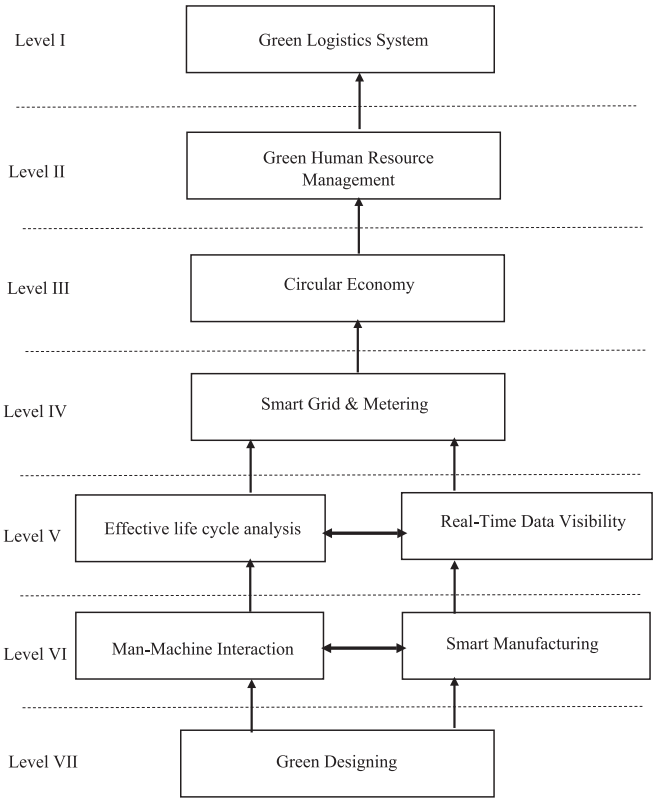

Fig. 2. ISM Based Model.

influence one another and rely on the elements in Level VI. To facilitate the collection of real-time data, industries must deploy smart manufacturing machines that are capable of supporting this data-driven approach.

In Level IV, the smart grid and metering system autonomously manages the power grid and makes rapid decisions based on real-time data. This factor emphasizes monitoring energy usage and efficiency, highlighting its reliance on the factors in Level V. Moving to Level III, the circular economy is dependent on the smart grid system, as it requires accurate data on energy waste and real-time visibility of generated waste to function effectively. By utilizing this data, the circular economy facilitates the recirculation and reuse of materials. In Level II, Green Human Resource Management (GHRM) adopts a company-wide approach to motivate, train, and guide employees through effective administrative control. GHRM leverages data, technology, and infrastructure to align organizational processes with sustainability goals in a controlled manner. Finally, the green logistics system at Level I represents an organizational strategy prioritizing sustainable transportation and logistical decision-making resources. The successful implementation of the green logistics system is influenced by lifecycle data regarding energy sources, power grid information concerning the modes of transport used, and smart inventory systems within manufacturing facilities.

Industry 5.0 technologies are intricately connected with GSCM practices, offering transformative solutions for sustainable industrial operations, especially within the context of the Bangladeshi RMG industry. The ISM-based model developed in this study was shared with expert members for validation and further discussion. The model was approved by the experts and provided critical insights. To further enhance the credibility of our findings, it is essential to gather empirical evidence supporting the impact of these synergistic factors. In the RMG sector, AI-driven predictive analytics optimize resource allocation and production scheduling, reducing excessive energy consumption and material waste common in fast-paced manufacturing environments. This leads to more efficient use of fabrics and energy resources, helping factories cut costs while minimizing environmental impacts (Zong and Guan, 2024). The IoT enables real-time tracking of raw material flows and energy use across production stages, providing factory managers with immediate insights into inefficiencies or excessive waste generation. In the Bangladeshi RMG industry, where energy consumption and emissions are significant challenges, these technologies allow for instant adjustments that directly contribute to reducing carbon footprints (Parvez et al., 2021).

Additionally, the use of advanced robotics in smart manufacturing enhances production precision by minimizing human error in fabric cutting and sewing, which are pivotal in garment production. This improvement not only boosts productivity but also curtails material wastage and unnecessary reworks, which are prevalent issues in traditional manufacturing setups (Wang et al., 2021). Through the implementation of smart manufacturing techniques like these, closed-loop systems can be introduced, ensuring that textile waste is recycled within the production cycle, reducing the industry's overall environmental footprint. For example, recycled fabric waste can be repurposed into new garments, promoting circular economy practices in the RMG sector. By integrating Industry 5.0 technologies with GSCM, Bangladeshi RMG industries can address specific environmental challenges while achieving sustainable industrial growth. These technologies create a robust foundation for a future-oriented, resource-efficient, and environmentally responsible RMG supply chain that directly contributes to sustainable development goals.

4.2. MICMAC analysis

The MICMAC analysis categorizes factors into four distinct groups based on their driving and dependence power, as illustrated in Fig. 3. The first category, *Autonomous Factors*, includes those with low driving and dependence power; however, no factors from this study fall into this category. The second category, *Dependent Factors*, encompasses factors with high dependency and low driving power. These factors rely on other elements for their achievement, such as Smart Grid and Metering (F), Circular Economy (I), Green Human Resource Management (H), and Green Logistics Systems (D). The third category, *Linkage Factors*, contains factors with both high driving and high dependency power. This study identifies Real-Time Data Visibility (B) and Effective Life Cycle Analysis (C) as Linkage Factors. Lastly, the fourth category, *Independent Factors*, includes those with high driving power but low dependence. These factors have a significant influence on the achievement of other factors; Green Designing (A), Smart Manufacturing (E), and Man-Machine Interaction (G) fall into this category.

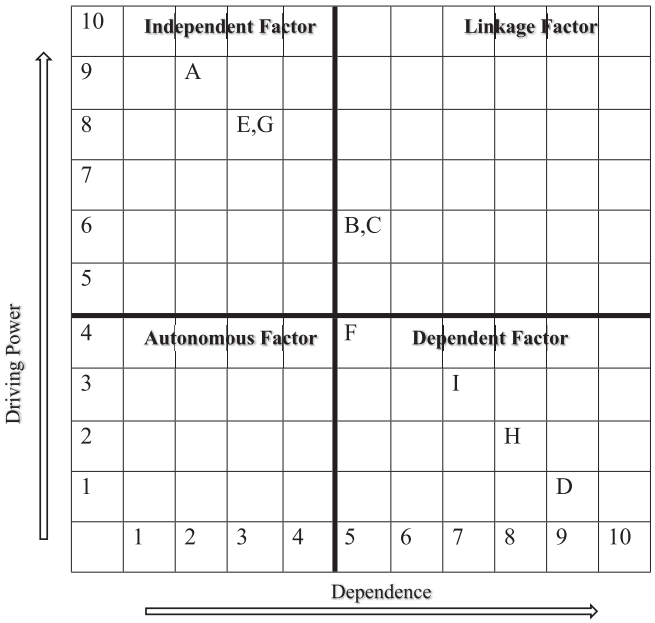

Fig. 3. MICMAC Analysis.

Understanding the placement of these factors in the MICMAC framework allows for strategic decision-making in SSCM adoption. For instance, focusing on Independent Factors can drive overall system improvements, given their influence over other areas. Similarly, addressing Linkage Factors is crucial due to their dual role in both driving and being driven by other factors. This analysis guides prioritization in the Bangladeshi RMG industry and provides a replicable framework for other sectors aiming for sustainable practices, emphasizing the critical pathways for integrating green technologies and Industry 5.0 elements into their supply chains.

4.3. Case analysis and insights

4.3.1. Case analysis

4.3.1.1. Case 1: Small-sized RMG manufacturer. A1 Ltd. is a small-sized RMG manufacturer specializing in eco-friendly apparel, facing challenges related to production inefficiencies and limited resources for adopting sustainable practices. The company aims to improve operations by integrating Industry 5.0 technologies and adopting GSCM practices. Based on the findings of this research, A1 Ltd. can utilize IoT for real-time monitoring and AI for predictive maintenance to minimize downtime and reduce resource wastage. Additionally, incorporating GSCM practices, such as sustainable sourcing and effective waste management, would bolster their sustainability efforts. The expected benefits include efficiency gains through IoT-enabled monitoring that optimizes production schedules and reduces energy consumption,

sustainability improvements via minimized waste and lower carbon emissions, and enhanced market competitiveness by meeting the global demand for eco-friendly products. These insights demonstrate how small-sized manufacturers can leverage the synergy between Industry 5.0 and GSCM to achieve operational efficiency, reduce waste, and enhance their sustainability profiles.

4.3.1.2. Case 2: Medium-sized RMG manufacturer. A2 Apparel is a medium-sized RMG manufacturer exporting to international markets and struggling with supply chain transparency and compliance with global sustainability standards. The company is keen to adopt Industry 5.0 technologies to streamline operations and improve its sustainability profile. This research suggests that A2 Apparel could enhance supply chain transparency by implementing blockchain technology while also utilizing collaborative robots (cobots) to improve worker safety and operational efficiency. Incorporating GSCM practices, including sustainable sourcing and energy-efficient technologies, would further strengthen their sustainability efforts. The anticipated benefits include increased transparency and accountability through blockchain-enabled traceability, improved operational efficiency via cobots, and significant sustainability impacts, such as reduced operational costs and environmental footprint, aligning with international standards. The case of A2 Apparel underscores the value of Industry 5.0 and GSCM in addressing transparency challenges, meeting global sustainability standards, and fostering resilience in competitive international markets.

4.3.2. Cross-case analysis

This study's cross-case analysis of several RMG companies in Bangladesh demonstrates the practical application of Industry 5.0 technologies and GSCM practices. The companies' varying size and operational scale serve as representative examples of the industry. The analysis focuses on integrating IoT, AI, and robotics technologies with GSCM strategies like waste reduction, energy efficiency, and supply chain transparency. Real-world implementations revealed key synergistic factors driving sustainable development. Companies adopting Industry 5.0 tools experienced enhanced operational efficiency, reduced environmental impact, and improved resource management. This analysis underscores the significant potential of the synergy between Industry 5.0 and GSCM to enhance sustainability within the Bangladeshi RMG industry. The findings provide a practical framework for industry stakeholders to integrate advanced technologies and green practices effectively, achieving specific sustainability goals and fostering long-term industrial resilience.

5. Implementation roadmap

The implementation roadmap for integrating I5.0 and GSCM in the Bangladeshi RMG industry outlines a structured approach to achieving sustainable development. Drawing from the findings of our ISM analysis, we identified key factors organized into seven hierarchical levels. These levels provide a phased strategy for implementation, but the strategic action plan itself is designed to offer practical steps that leverage the synergy between I5.0 and GSCM. The MICMAC analysis supports the phased implementation of synergistic factors by categorizing them based on their driving and dependence power. High-driving power factors like Green Designing, Smart Manufacturing, and Man-Machine Interaction are prioritized in the initial phases of the roadmap due to their critical influence on the successful integration of GSCM and I5.0. In contrast, factors with higher dependence, such as Circular Economy and Smart Grid Systems, are planned for later phases, as they depend on the foundational success of earlier implementations. This structured prioritization ensures that the roadmap progresses efficiently while first addressing the most influential elements. This roadmap aims to guide the RMG sector towards achieving the SDGs through this integration.

5.1. Strategic action plan

A SWOT analysis reveals valuable insights for developing a strategic action plan in the Bangladeshi RMG sector. Capitalizing on strengths in green design prioritizing, cross-functional collaboration, and a priority-based budget allocation system is critical. These strengths should be augmented by fostering better collaboration between departments and enhancing technological integration. Targeted research and expert consultations must address weaknesses resulting from an imperfect grasp of the drive and dependent linkages. The strategic action plan should concentrate on capturing opportunities that arise from coordinating business operations with environmental objectives and transforming corporate governance frameworks in the direction of stakeholder capitalism. This involves developing quantifiable indices for tracking progress towards sustainable development goals. Finally, to mitigate threats posed by environmental crises and increasing legal pressures, organizations must engage in R&D, adopting sustainable practices and technologies. They should also diversify their energy sources and improve resource efficiency, making them less vulnerable to external threats.

To ensure successful implementation, several strategic steps are recommended:

- Begin with pilot projects focusing on Green Designing and Smart Manufacturing to demonstrate the environmental and economic benefits of I5.0 and GSCM integration.
- Train workers in the RMG sector to work effectively alongside advanced Industry 5.0 technologies, promoting both environmental sustainability and worker well-being.
- Engage key stakeholders, including suppliers, retailers, and government bodies, to ensure that the benefits of this synergy are realized across the entire supply chain.
- Collaborate with the government to develop policies and incentives that encourage the adoption of green technologies and practices, supporting the industry's shift towards sustainability.

These initiatives will lead to a demonstrably reduced environmental footprint, enhanced brand image for eco-conscious consumers, and improved production efficiency through minimized waste. The strategic plan for sustainable growth should be iterative and flexible to changing circumstances in the growing landscape of I5.0 and GSCM landscape, positioning the Bangladeshi RMG industry for a future that is both environmentally responsible and economically prosperous.

5.2. Monitoring and feedback mechanism

The roadmap emphasizes continuous monitoring and feedback mechanisms using AI-powered analytics to track progress, adjust strategies and ensure alignment with the sustainable development goals. This will help the RMG industry in Bangladesh to not only adopt sustainable practices but also maintain them, creating a resilient and sustainable RMG sector.

6. Contributions to sustainable development goals

This research directly supports several Sustainable Development Goals set by the United Nations by offering a structured roadmap for the Bangladeshi RMG industry to achieve sustainability through the integration of I5.0 and GSCM. The alignment between the proposed strategies and specific SDGs is outlined below, demonstrating how these initiatives contribute to global sustainability efforts:

- **SDG 9: Industry, Innovation and Infrastructure:** This research promotes Industry 5.0, a new era of sustainable and human-centric industrial practices. By leveraging I5.0 technologies, RMG

industries can optimize GSCM practices and contribute to building a more sustainable infrastructure.

- **SDG 12: Responsible Consumption and Production:** A core principle of GSCM is minimizing environmental impact throughout the supply chain. This research investigates how I5.0 tools like real-time data monitoring and smart tracking systems can be used to monitor and improve GSCM initiatives. This can lead to more responsible consumption and production patterns within the RMG sector, potentially reducing waste and optimizing resource use.
- **SDG 13: Climate Action:** The urgency of addressing climate change necessitates more efficient and sustainable industrial practices. This research explores how the synergy between I5.0 and GSCM can contribute to this goal. The proposed strategic action plans, focusing on green design principles and a circular economy model, can lead to reduced greenhouse gas emissions and a demonstrably reduced environmental footprint within the Bangladeshi RMG industry.

This research aligns with several SDGs by promoting sustainable development in the RMG industry through the integration of I5.0 and GSCM practices. By focusing on innovation, responsible consumption and production, and climate action, this research contributes to a future where the RMG sector plays a positive role in achieving global sustainability goals.

7. Conclusion

The rapid growth of the Bangladeshi RMG industry has come at a significant environmental cost. Greenhouse gas emissions and global warming pose a serious threat, potentially pushing the Earth past a critical threshold within a decade (Plumer, 2023). The Paris Agreement highlights the urgency of action, with 1.5 degrees Celsius as the maximum limit for global warming to avoid catastrophic consequences like food shortages, extreme weather events, and ecosystem collapse (Matemilola et al., 2020). Despite a 1.1-degree Celsius rise and alarming signs like severe weather patterns and pandemics, our current efforts are insufficient. A robust and scalable solution is needed to avert disaster, combining technological advancements with robust GSCM practices. Following COP 27, a global commitment of nearly $3 trillion USD by 2030 aims to develop mitigation strategies (COP27, 2022. The effective allocation of these resources is crucial. This study provides a roadmap for RMG industries in Bangladesh, focusing on integrating Industry 5.0 technologies with GSCM. Our research identifies “Green Design” as the most critical factor for achieving sustainable development goals. By prioritizing green design principles and implementing the strategic action plans outlined earlier, the Bangladeshi RMG sector can contribute significantly to environmental sustainability while ensuring continued economic growth.

The research objectives are achieved through a structured approach that integrates I5.0 technologies with GSCM practices, specifically targeting sustainability in the Bangladeshi RMG industry. The study begins by identifying key synergistic factors through an extensive literature review and consultations with experts. An ISM approach will then be applied to analyze these factors’ relationships and relative importance, facilitating a clear understanding of how technologies can enhance GSCM. To validate these findings, this research proposed pilot projects focused on green designing and smart manufacturing will demonstrate the practical impact of these technologies on environmental and economic outcomes.

7.1. Contribution of this research

This research offers a significant contribution to Bangladeshi RMG industries in pursuit of sustainable development goals. Recognizing the gap in I5.0 adoption for developing nations provides a roadmap for integrating I5.0 with GSCM practices specific to the RMG sector. The research highlights Green Design as a fundamental pillar of sustainability and presents a well-defined hierarchy of other key factors that drive the transition to sustainable practices. By uncovering the synergies between Industry 5.0 and GSCM, this study provides RMG companies with a comprehensive framework to adopt a sustainability-focused approach. The emphasis on sustainable corporate governance ensures that environmental responsibility is integrated with economic growth. This future-oriented approach positions the Bangladeshi RMG sector to thrive in a world demanding competitiveness and environmental consciousness. This research not only aligns with several SDGs but also proposes a practical framework for the Bangladeshi RMG industry to embrace sustainable practices. The industry can contribute to a more sustainable future while maintaining economic growth through focused action plans, collaboration among stakeholders, and continuous improvement.

7.2. Managerial implication

The Bangladeshi RMG industry is at a critical point of transformation, where prioritizing environmental sustainability has become essential. Managers can no longer rely on traditional practices and must now integrate sustainable initiatives into every facet of their operations. This research provides a strategic roadmap to guide managers through this transition, helping them make informed decisions by identifying and prioritizing key sustainability factors and understanding their interdependencies.

By focusing on environmental responsibility and aligning with the principles of Industry 5.0, which emphasizes human-centered and sustainable manufacturing, this study equips managers to foster innovation. Through the ISM based model and MICMAC framework, managers can pinpoint which factors are critical drivers or dependents of successful I5.0 and GSCM adoption, enabling them to prioritize investments in green technologies and practices effectively. This proactive approach will help managers stay competitive in an increasingly eco-conscious global market while advancing sustainability goals. Additionally, this research encourages a cross-functional approach, drawing on expertise from environment, health and safety (EHS), supply chain, production, and academia. Traditionally, the EHS team focuses on sustainability metrics, while supply chain teams prioritize production and delivery. This research bridges that gap by involving all these functions, leading to a holistic approach to decision-making. This inclusive approach not only strengthens the reliability of the research but also provides managers with actionable insights to engage their teams more effectively in sustainability efforts.

Moreover, the study underscores that sustainability is not limited to environmental concerns alone. It also incorporates social and economic dimensions, encouraging managers to view sustainability through a broader lens, ensuring that initiatives align with Sustainable Development Goals and corporate social responsibility. This holistic approach enables RMG managers to become proactive leaders, championing the integration of green practices and I5.0 technologies to drive sustainable growth and long-term competitiveness.

7.3. Limitations and future scope of development

This study identified key functions within the RMG industry that can contribute to sustainable growth under the framework of Industry 5.0. Employing the ISM technique, it predicted the development of these functions and explored their potential interactions. However, several limitations must be considered when interpreting the findings. First, while the study successfully mapped out the sequential relationships between functions, it did not quantify the strength of these connections due to the inherent limitations of the ISM methodology. As a result, the strategic roadmap is constrained to the specific context in which it was developed, limiting its generalizability. Additionally, although the ISM technique enabled the identification of relationships between factors, it could not decisively measure the strength of these links, preventing the

study from offering more precise guidance on interactions between key sustainability functions. Furthermore, the study's framework is based on early literature on Industry 5.0, indicating that as Industry 5.0 evolves, the depth and breadth of sustainability-related functions will likely expand. Future research will need to consider these advancements to refine and extend the study's findings.

Given these limitations, future research in the Bangladeshi RMG industry can make several valuable contributions. First, conducting industrial-level case studies will be essential to examine the relationships between factors in real-world settings. As Industry 5.0 matures, it will be crucial to reevaluate and validate the prioritization of factors through practical applications and case studies. Additionally, future research should focus on quantitatively assessing the strength of connections between functions, as providing numerical insights can offer more robust decision-making tools for managers to prioritize sustainability efforts effectively. Lastly, future studies should identify and address potential barriers encountered while implementing these factors, considering both industrial and socio-economic perspectives. By outlining mitigation strategies for these barriers, future research can enhance the applicability and success of the proposed framework.

CRediT authorship contribution statement

Md Al Amin: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Arka Chakraborty:** Writing – original draft, Methodology, Conceptualization. **Roberto Baldacci:** Writing – review & editing, Supervision.

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Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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