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A structural equation modeling framework for exploring the industry 5.0 and sustainable supply chain determinants

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ABSTRACT

Sustainable Supply Chain and Industry 5.0 are two important concepts reshaping how businesses operate in the modern world. Together, these two concepts drive the advancement of a highly sustainable and robust worldwide economy. Companies are now becoming more sustainable in supply chain management, using technologies like blockchain and co-bots to track the origin of goods, ensure ethical and sustainable sourcing, and work with humans safely and effectively. This study develops a theoretical model highlighting the determinants of Industry 5.0, Sustainable Supply Chain Practices, by combining theoretical frameworks from the manufacturing, supply chain, and information systems literature. The study's analytic sample comprises 342 responses collected from professionals working in the electronics industry's supply chain. Hypotheses were constructed employing deductive reasoning, leveraging insights gleaned from prior research. The study is conducted utilizing the Structural Equation Modeling (SEM) to substantiate the presumed connections among various constructs, namely, Industry 5.0 innovations, Sustainable Supply Chain Practices (SSCP), Sustainable Supply Chain Performance (SCP), and Supply Chain Risks (SCR). The Structural Equation Modeling analysis results show a direct impact of Industry 5.0 technologies through Sustainable Supply Chain Practices can enhance Supply Chain Performance and mitigate Supply Chain Risks. Combining the two paradigms can foster the development of new business models that prioritize sustainability and contribute to a more equitable and environmentally friendly economy that brings positive change for both businesses and society.

1. Introduction

Given the rise of the idea of Industry 5.0 and the increasing significance placed on environmentally responsible supply chains, businesses are experiencing significant changes in how they operate and produce commodities. Bayanati [6]. For instance, traditional industrial processes are being revolutionized due to the innovative use of cutting-edge technology in fields such as robot, The Internet of Things (IoT), artificial intelligence (AI). This trend is expected to continue as technological progress accelerates (Wang et al., 2022). Additionally, the need to regulate the flow of goods, services, and data in a way that reduces environmental impact while also considering social and economic considerations is also becoming more and more apparent. (Saglam et al., 2021). Therefore, sustainability and Industry 5.0 should work in tandem to improve global supply chain transparency, efficiency, and cooperation. This would also encourage sustainable business strategies promoting a fairer and greener economy. Fraga-Lamas et al., [25].

Although numerous approaches have been employed to study sustainability in recent years, Industry 4.0 still needs to prioritize environmental protection or technology that enhances the sustainability of the planet. Prior research that has fused AI algorithms with environmental management has facilitated the development of this endeavor, but a better technical solution is required to preserve the environment and promote sustainability [82]. This solution is expected in Industry 5.0. The Fifth Industrial Revolution (I5.0) strives to bring back human workers into manufacturing facilities. to combine processes with

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intelligent technology to maximize human brainpower and creativity [20]. Unlike Industry 4.0, which emphasizes automation, Industry 5.0 will integrate people and autonomous robots. The autonomous workforce follows the goals and desires of human. This will guide us to a more productive and worthwhile production process, boost confidence in autonomy, and cut down on waste. and expenses [21]. Environmental management is an essential component of any robust supply chain, and even Industry 5.0 must adopt it if they want to remain competitive. along the value chain from raw materials to finished goods in order to dematerialize, decarbonize, and detoxify it. Hu et al., [39].

The concept of Sustainable Supply Chain Management is quickly becoming a forefront strategy for companies looking to reduce their environmental impact [48,52]. One aspect of a product's lifecycle that can be considered a part of sustainable supply chain practices is the adoption of techniques that are both environmentally friendly and socially responsible. Chandra, Kumar [13]. Sustainable Supply Chain Management includes the practice of a "Green Supply Chain" which includes reuse, remanufacturing, recycling, green design, green procurement, total quality environmental management, environmentally friendly packaging, transportation, and end-of-life product management [8]. Innovative technologies like the Internet of Things (IoT) and blockchain enable the supply chain to monitor items and data in real-time. As a result, businesses are better equipped to anticipate and prepare for challenges related to packing, transportation, and the management of products' end-of-life cycles, such as bottlenecks. Ghadge [27].

Along with the improvement of Supply Chain Performance, there is also some Supply Chain Risks factors incorporated in the context of Industry 5.0. In Industry 5.0, where cyber-physical systems intertwine with production processes and data security is paramount, vulnerabilities in these systems become significant risk factors [16]. Problems arise when technology advances at a startling rate; supply chains must be flexible to keep up [36,45]. These factors underscore the importance of implementing robust risk management approaches to navigate the complexities of an ever-evolving and interconnected industrial landscape. In this study, we first attempted to integrate Industry 5.0 with different dimensions of Sustainable Supply Chain Practices, followed by applying Structural Equation Modeling in order to determine the reliability of the factors important to the Industry 5.0 electronic industry. To elaborate, this study develops a theoretical model that aggregates all the factors and subfactors of *Industry 5.0 (I5.0), Sustainable Supply Chain Practices (SSCP), Sustainable Supply Chain Performance (SCP), and Supply Chain Risks (SCR)* within the electronics industry by combining theoretical frameworks from manufacturing, supply chain, and information systems personnel interviews and existing literature. To that end, five hypotheses were developed to construct a Structural Equation Modeling that expressed in terms a relationship diagram among the five main factors and depicts their impact on each other and prioritize the most important sub-factors to increase supply chain performance. The survey's validation was carried out using confirmatory factor analysis. Industry 5.0 innovations, Sustainable Supply Chain Practices, Sustainable Supply Chain Performance, and Supply Chain Risks were the factors that were compared in this approach to models that had previously been validated by Granié et al. [31] and Papadimitriou et al. [75]. The following section covers the most recent research on Industry 5.0, Sustainable Supply Chain Practices and related works based on Supply Chain Performance and Supply Chain Risks. Section 3 outlines the hypotheses development. Section 4 describes the research methodology which is followed to data analysis in Section 5. Finally, discussion and conclusion with future scopes of the study are discussed in Sections 6 and 7, respectively.

2. Literature review

This section discussed the extant review of literature on Industry 5.0, Sustainable Supply Chain Practices, and Sustainable Supply Chain Risks agendas.

2.1. Related work based on Industry 5.0 and sustainable supply chain practices

Ghobakhloo et al. [28] laid out a roadmap for achieving sustainable development within the framework of Industry 5.0, highlighting human-centricity, socio-environmental sustainability, and resilience as key components of this new paradigm, which promises to move away from the profit-centered productivity of Industry 4.0 and towards the promotion of sustainable development goals. The importance of knowing how Industry 5.0 turns its abstract sustainability claims into real benefits has been discussed by Ghobakhloo et al. [28]. Using interpretive structural modelling (ISM), they laid out a plan for the future and a model for sustainable development made possible by Industry 5.0. In a parallel exploration of the Industry 4.0–5.0 transition, Kazancoglu et al. [47] carried out an in-depth investigation into textile and apparel supply chains. Using a fuzzy DEMATEL approach, they identified and prioritized critical challenges, offering insights crucial for similar studies in this sector. Simultaneously, Prassida and Asfari [78] delved into the dynamics of job disengagement on par with Industry 5.0, developing a structural equations model. In a related study, a PLS-SEM model for an adoption-implementation framework for digital green was introduced by Yin et al. (2022) as a supplementary effort, with the goal of improving digital green innovation within the Industry 5.0 landscape. Rachmawati et al. [79] shifted the focus to student resilience amid industry transitions, utilizing a survey and proportional stratified random sampling to gauge the resilience of 116 social science students. Addressing broader societal challenges, Golovianko et al. [30] proposed a hybrid Industry 4.0-Industry 5.0 model that combines automation and human-driven processes. Environmental considerations were underscored by Sharma et al. [90], advocating for circular supply chain (CSC) paradigms to foster sustainability. In the pursuit of sustainable development, Dwivedi et al. [20] unveiled significant insights into the dynamic interplay between Industry 5.0 and the Circular Supply Chain. By recognizing and delineating the intricate interactions, the study provides a comprehensive understanding of how these elements collaborate synergistically, offering valuable implications for achieving sustainability goals. Singh et al. [92] aligned with the Industry 5.0 revolution, emphasizing intelligent manufacturing and its potential as a catalyst for sustainability within a circular economy. Technological advancements played a significant role, notably incorporating Blockchain technology into supply chains, as highlighted by Rahman et al. [81]. Yadav et al. [105] stressed the integration of BC and supply chain practices for sustainability. Attempting to address the carbon footprint, the "Green IoT" paradigm faced challenges conflicting with the power-intensive goals of "Edge AI," as explored by [25]. Real-world applications of Industry 5.0 concepts were exemplified by Yadav et al. [105], showcasing an Industry 5.0 smart workshop prioritizing worker safety and data tracking. Golgeci et al. [29] provided a method to determine intrinsic motivation and external encouragement's importance in the success of sustainability initiatives, specifically in the Indian oil and gas sectors. Mustofa [66] employed Structural Equation Modeling to identify factors causing the Bullwhip Effect in the food-based industry supply chain, revealing vulnerabilities exacerbated. By presenting "The Resilient Operator 5.0" idea, Romero, Stahre [85] foretold how smart resilient industrial systems would employ workers in the future. Frederico [26] highlighted the collaboration between robots and human cognition in Industry 5.0, introducing the concept of a "co-bot" pivotal to the next industrial evolution. Karmaker et al. [46] and Abualigah et al. [1] emphasized the motivations behind Industry 5.0 and Sustainable Supply Chain Practices, aiming to enhance efficiency, competitiveness, and sustainability. By incorporating these principles and practices into operations, organizations can establish a supply chain that is both more robust and sustainable, catering to the demands of customers, stakeholders, and society [3]. Human-centeredness, sustainability, and resilience were identified as the three interdependent foundations underlying the key principles of I5.0 [84]. Despite the rising popularity of Industry 5.0, research is still in its infancy, particularly in underdeveloped nations [64]. To bridge this gap, Mukherjee et al. [64] systematically identified barriers, ranked them empirically, assessed organizational interdependencies using the decision making trial and evaluation laboratory (DEMATEL) method, and proposed the Green, Resilient, and Inclusive Development (GRID) framework to surmount these barriers.

2.2. Related work based on supply chain performance and sustainable supply chain risks

Rosyidah et al., [86] provided insights of a diagnostic tool named as SCOR (Supply Chain Operations Reference) model which assess the Green Supply Chain Management (GSCM) performance using the green score model. Resulting in a waste reduction rate of 48 percent in crude palm oil water content. Previously, Chandra and Kumar [13] presented a novel framework demonstrating the application of key performance indicators for the vaccine supply chain (VSC). This framework illustrates how the Universal Immunization Program in India can align with the Sustainable Development Goals. The learning and growth, internal process, customer, and financial dimensions were used to analyze the performance indicators using the balanced scorecard (BSC), whereas the economic, environmental, and social dimensions were used to evaluate sustainability practices criteria (SPC) [13]. In contrast to earlier research, Soto Lopez et al. [94] specifically scrutinized the internal performance indicators of hospital supply chain. The focus was on understanding the interdependencies within and determining key performance metrics for each logistics process element to enhance its internal operations. Their proposed methods combine group Decision-Making and Trial Evaluation Laboratory (DEMATEL) method and rough set theory, [94]. In order to assess different parts of the supply chain and provide more accurate indications, Narimissa et al. [68] created a long-term performance assessment system. All three dimensions of sustainability—economic, ecological, and social—are included in the evaluation. Moving on to the technological advancement in the recent industrial evolution, Bayanati [6]. identified and assessed important dimensions, components, and performance metrics in information logistics and intelligent supply chains. Ivanov [43] in their recent work introduced the most up-to-date Industry 5.0 framework focusing on the most essential parts of technology and organizational structure. According to Kurdi et al. [51], organizational performance is strongly associated with supply chain risks management. A study by Waqas et al., [102]. has shown how small-scale agropreneurs in Malaysia can eliminate hazards and increase performance through supply chain risks management using partial least squares structural equation modeling. Nguyen et al. [71] investigated the dynamics of business performance within the Vietnamese pharmaceutical industry in the midst of the COVID-19 pandemic, focusing on supply chain risks, integration, and resilience. For the investigation, smart PLS software was utilized. Later, Munir et al. [65] investigated the role of supply chain risks management as a mediator between supply chain integration (SCI) and organizational performance using Covariance-based structural equation modeling. Another study by Can Saglam et al. [11] found that supply chain resilience and responsiveness greatly affect risk management performance, but not flexibility. Contrary to literature, risk management culture does not reduce these connections. The study by Hussain et al., [41] employed a survey-based methodology utilizing questionnaires to collect information from a business organization in Turkey. The data are examined utilizing the methodology of partial least squares (PLS).

Existing literature clearly highlights various research studies exploring the concepts and analyses of Industry 5.0 and Sustainable Supply Chain. However, a noticeable research gap exists in understanding the determinants of Sustainable Supply Chain Performance and Supply Chain Resilience within the framework of Industry 5.0, and how the collaboration between Industry 5.0 and Sustainable Supply Chain Practices can enhance organizational supply chains while mitigating Supply Chain Risks. To address this gap, this study intends to systematically aggregate and categorize all factors relevant to Industry 5.0 and Sustainable Supply Chain Practices. This research will give insight to the researcher and practitioner about identifying the most crucial factors to smoothly implement the practice of sustainable supply chain in the Electronic based industry in the context of Industry 5.0. The contributions made by this research are as follows:

- Explore Industry 5.0 and sustainable supply chain management determinants.
- Study sustainable supply chain practices and risks in Industry 5.0.
- Develop a new model depicting dependence and co-relation between Industry 5.0 and sustainable supply chain management.
- Investigate the dependence effect by examining how one factor directly or indirectly impacts another.
- Prioritize the most critical sub-factors related to each factor in the proposed framework.

In sum, a new model is also developed to depict the dependence and co-relation between Industry 5.0 and Sustainable Supply Chain Performance; and investigates its dependence effect to one another. The study aims to assist professionals in establishing a sustainable supply chain infrastructure within the context of Industry 5.0. Academician and people related to industry will know the most critical sub-factors related to this context and can take actions adeptly to assure seamless supply chain operations. This model helps businesses set up strong and sustainable supply chains in Industry 5.0 era. The benefits go beyond just companies — understanding these important factors can also boost a country's economy.

3. Hypotheses development

After reviewing the literature, we have aggregated and categorized all the related factors as shown in Appendix A and 5 Hypotheses were proposed to establish the correlation between the two paradigms: Industry 5.0 and Sustainable Supply Chain Practices. The hypothesized relationship between Industry 5.0 and Sustainable Supply Chain Practices was tested using data obtained from a survey. Here are the hypotheses that have been suggested.

3.1. Industry 5.0 and sustainable supply chain practices

The Industry 5.0revolution uses a network of interconnected systems and devices throughout the supply chain to enable smart manufacturing in accordance with client-specific needs. Sustainable Supply Chain Performance is being implemented to a far greater extent thanks to the technical advancements made in the Industry 5.0 era. In order to make supply chain operations more efficient, transparent, and sustainable, innovations like blockchain, AI, the Internet of Things (IoT), and big data analytics are crucial. AI and predictive analytics optimize logistics, inventory management, and demand forecasting, reducing waste and improving resource allocation. Through the utilization of blockchain technology, supply chains see enhanced levels of traceability and transparency. Empowering ethical sourcing practices and the verification of sustainable processes. Amid the Covid 19, Karmaker et al. [46] analyzed that the people in the decision making should redesign their conventional supply chain networks to modern information driven supply chain networks by creating and adopting new cutting-edge technologies to guarantee company continuity in the post-COVID-19 era. To that end, the traditional organizations can adopt Industry 5.0 technologies, as it has gained popularity over the world nowadays for creating robust and accessible operations by assuring long-term supply chain sustainability through its different noteworthy features. So here comes our first hypothesis:

H1. : The adoption of Sustainable Supply Chain Practices is correlated positively with technological advancements in the Industry 5.0 era.

3.2. Industry 5.0, sustainable supply chain practices and supply chain performance

As sustainability and resilience become increasingly important, academics and practitioners are developing tactics and skills to address the difficulties linked to the sustainability of the supply chain and contribute to setting up a sustainable supply chain as well as increasing its performance. Industry 5.0 signifies the forthcoming stage of industrial advancement, bringing about a positive transformation in Sustainable Supply Chain Practices. This paradigm shift integrates high end technologies such as artificial intelligence and the Internet of Things (IoT), and automation with a renewed emphasis on human-centric approaches. In addition to enhancing efficiency in supply chain operations, Industry 5.0 places a vital significance on ethical considerations, environmental responsibility, and social awareness. By integrating human ingenuity with technological advancements, Industry 5.0 helps in the development of longer-lasting and efficient supply chains. It enables enhanced monitoring, predictive analytics, and decision-making capabilities, fostering better resource utilization, waste reduction, and ethical sourcing practices across the supply chain. This evolution supports the transition towards circular economy principles, encouraging practices like product refurbishment, recycling, and remanufacturing, thereby reducing environmental impact. Through its emphasis on collaboration, innovation, and responsible practices, Industry 5.0 plays a significant role in elevating and advancing Sustainable Supply Chain Practices for a more sustainable future. That being said, we can assume our second and third hypotheses, and they are:

H2. : The influence of Industry 5.0 correlates positively with Supply Chain Performance.

H3. : Sustainable Supply Chain Practices mediates the relationship between Industry 5.0 (I5.0) and the improvement of Supply Chain Performance.

3.3. Industry 5.0, sustainable supply chain management and supply chain risks factors

Industry 5.0 is an encouraging framework that can help reduce some of the factors that contribute to Supply Chain Risks. Incorporating cutting-edge tech like machine learning, artificial intelligence, and IoT sensors, Industry 5.0 allows supply chains to make quick decisions based on predictive analytics and real-time monitoring. These tools provide a comprehensive view of operations, allowing for the identification of potential risks such as disruptions in logistics, supplier dependencies, or environmental factors. The real-time resource consumption monitoring and optimization capabilities of Industry 5.0 have the potential to cut down on resource waste. It enables a rapid response to quality issues or customer complaints and provides SC transparency and accountability, all of which combine to reduce the risk of losing market share as well as reputation.

In order to reduce the likelihood of product loss, theft, or damage, businesses can use IoT sensors and RFID tags to track products throughout the supply chain, according to Romero, Stahre [85]. AI, blockchain, and big data analytics are at the forefront of Industry 5.0's push towards supply chain visibility and efficiency. Potential dangers can be identified and mitigated by supply chain managers through the analysis of data from a variety of sources, including social media, economic indicators, and weather trends. Mukherjee et al. [64] found that the increased visibility offered by Industry 5.0 allows organizations to monitor supply chain performance in real-time, positively impacting overall supply chain management. From their work, we can assume our fourth and fifth hypotheses as:

H4. *: Industry 5.0 is positively associated with mitigating Supply Chain Risks factors.*

H5. *: Sustainable Supply Chain Practices mediates the relationship between Industry 5.0 and mitigation of Supply Chain Risks factors.*

4. Research methodology

This study was conducted on 13 different electronic industries in Bangladesh, and practitioners from all fields (manufacturing, supply chain, quality, marketing and finance) participated. The list of reasons and descriptions for each construct was submitted to 26 executives from the electronics industry sector. For the validation purpose, the questionnaires were developed to evaluate these factors, and the participants were asked to review the questionnaires for face validation purposes, as well as to provide feedback on the wording and clarity of each question.

The questionnaires were set up on Google Forms and sent to participants via email and social media messaging platforms. Every question is evaluated using a Likert scale that spans from 1 to 5. A rating of 1 indicates a strong disagreement, while a rating of 5 indicates a strong agreement. along with obtaining participant consent, data confidentiality, and anonymity. Furthermore, participants were encouraged to provide any additional guidelines or to eliminate certain items if they deemed them redundant or inappropriate. Finally, the final set of questionnaires was sent to 754 participants, of which 62% provided feedback, while 77 feedbacks were rejected due to incomplete submissions. A total of 390 responses data were then entered into SPSS 24.0 (Statistical Packages for Social Sciences). A total of 48 data points had either missing values or outliers. After excluding these 48 data points, 342 data points were selected for analysis. Among the participants, 53.39% were in the 24–36 age categories, 33.97% were in the 37–50 age category, and 12.64% were above 50 years of age. Approximately 65.35 percent of the respondents were males, while 34.65 percent were females.

For Structural Equation Modelling analysis, In'nami and Koizumi [42] state that a sample size of more than 200 answers is sufficient, Hence, according to this study, we are satisfied with our final data feed. SPSS and AMOS software were used to assess the data. In order to analyze the data, two primary steps were undertaken: first, measurement construct validity, discriminant validity, and convergent validity were examined; second, the structural model was examined in accordance with Hair et al., [34] recommendations.

4.1. Instrumentations

In developing our model, we have considered 4 main factors, Industry 5.0 (I5.0), Sustainable Supply Chain Practices (SSCP), Supply Chain Performance (SCP), Supply Chain Risks (SCR). These 4 main factors have been subcategorized by reviewing the extant literature review. Industry 5.0 main factors have been subcategorized into 12 subfactors, 16 subfactors have been identified within Sustainable Supply Chain Practices, five subfactors have been identified within Supply Chain Performance, and Supply Chain Risks have been subcategorized into 14 sub-factors. 12 sub-factors of Industry 5.0 were adapted from Nahavandi et al., (2019), Rahate et al., [80], Massaro et al., (2021), Ordieres-Meré et al., [73], Gupta et al., [32], Shahbazi & Byun, [89], Wang et al., [100], Modoni & Sacco, [62], Singh et al., [92], Locklin et al., [57], Brunzini et al., [9], Chen et al., [14], Chander et al., [12], Maddikunta et al. [59], Pizoń & Gola [76], Leng, Sha et al. (2022), Verma et al., [98], Chi et al., [15], Zeb et al., [107], Koroglu, [49], and Mourtzis et al., [63]. To measure Sustainable Supply Chain Practices, 16 items were collected from Redchuk et al., [83], Fraga-Lamas et al., [25], ZengiN et al., (2023), Yin & Yu [106], Hu et al., [39], Draghici & Ivascu, [19], Li & Song, [56], Oláh et al., [72], Sun et al., [96], (Raut, Narkhede et al. (2017), Dong et al., [18], Mishra et al., [61], Habib et al., [33], Golgeci et al. [29], Bentahar et al., [7], Shooshtarian et al., [91], Panagiotopoulou & Stavropoulos, [74], Yadav et al. [105], Krishnan et al., [50], Prasad et al. [77], and [37,38]. The 5 sub-factors SCP are adapted from Ghadge et al. [27], Sakib et al., [87], Lee et al., (2021), Rachmawati et al. [79], and Huang et al. [40]. For the Supply Chain Risks items, 14 items were referenced from Nayeri et al., [70], Wu et al., [104], Ahmadiahangar et al., [2], Zhong et al., [109], Bae et al., [5], Wang, Zhuo [101], Tripathi et al., [97], Wie et al., (2020), Villoria et al., [99], Fracarolli Nunes et al., [24], ElFar et al., [21], Javaid et al., [44], Helm et al., [35], Sukmono and Junaedi [95].

5. Data analysis and findings

The collected data was subjected to a two-stage analytical procedure. The measurement model's validity, fit, and reliability were assessed using a Confirmatory Factor Analysis (CFA) in the first stage of the analysis. After that, we tested our hypothesis by estimating the structural model with a structural equation model (SEM). There were additional multigroup analyses and considerations of non-response bias in this study.

5.1. Non-response bias test

This study employed t-tests to examine the presence of response and non-response biases. Specifically, the similarities between the mean and standard deviation were compared for early and late replies in the primary variables. According to the data presented, 230 participants were considered to have provided early responses and 60 were considered to have provided late responses. Levene [55] determines whether there is a notable difference in the homogeneity of variances between the early and late responses for each variable. In this case, the test suggests that there is no significant difference in terms of homogeneity of variances. The results presented in Table 1 demonstrate that the usable sample is not influenced by non-response bias. Therefore, both early and late responders in this study correctly represent the same target demographic.

5.2. Validating the Measurement Model

All measurement constructs were analyzed using confirmatory factor analysis (CFA) which is carried out by SPSS Amos software. When performing a measurement model analysis, we used maximum likelihood estimation procedures to evaluate the accuracy of our model estimates in accordance with predefined goodness-of-fit standards like the Goodness of Fit Index (GFI) and the Comparative Fit Index (CFI). From Table 2, we found out that the values of GFI and CFI are over 0.90 (GFI = 0.927; CFI = 0.953), which indicates a good model fit index according to Byrne [10]. Dillion and Goldstein (1984) emphasized the importance of considering an item's "loading" and value when interpreting factors. SPSS® is used to measure Kaiser- Meyer- Olkin (KMO) value to determine the sampling data's adequacy. From Table 2, we found out that all factors' KMO value is over 0.6, and according to De Guimarães et al. [17], KMO value greater than 0.6 is acceptable to perform factor analysis. By assessing the Corrected Item Total Correlations (CITC), Churchill (1979) found that the items could be filtered. According to Cronbach (1951), SPSS® used to remove items/factors if their impact on the model was minimal under Cronbach's alpha consideration. To demonstrate item reliability and factor uni-dimensionality, all standardized factor loadings must be higher than 0.50. After factor analysis, the aggregated factors and sub-factors that stand out as valid and significant (CITC, KMO >0.5, and Cronbach's > 0.70) are shown in Table 2. In addition, significance analysis is used with Bartltet's test to evaluate the feasibility of the variables. According to Armstrong and Soelberg [4], a factor is labeled significant if Bartlett's value is less than 0.05. Table 2 showed that all the construct's items (Industry 5.0, Sustainable Supply Chain Practices, Sustainable Supply Chain Performance, and Supply Chain Risks) were subjected to exploratory factor analysis as a group to

Table 2
Industry 5.0, Sustainable Supply Chain Practices, Sustainable Supply Chain Performance, and Supply Chain Risks Factors Measurement.

Factors	Sub-Factors	CITCs	Cronbach's α	KMO Measure of Sampling	Bartlett's Test of Sphericity Significance
I5.0	MCAST	0.648	0.725	0.716	0.000
	DT	0.652			
	SFT	0.532			
	VT	0.52			
	IAS	0.763			
	EC	0.652			
	CBTS	0.503			
	IOE	0.696			
	BC	0.501			
SSCP	EC	0.66	0.743	0.670	0.000
	GM	0.686			
	LCHM	0.663			
	RL	0.664			
	ECC	0.706			
	CAGI	0.802			
	HS	0.624			
	GD	0.772			
	SPP	0.685			
	CFPR	0.664			
	GP	0.725			
	CRS	0.647			
	WPST	0.739			
SCP	ENVF	0.69	0.708	0.609	0.000
	ECF	0.632			
	OF	0.632			
	TCHF	0.53			
	SOF	0.724			
SCR	DSU	0.757	0.702	0.766	0.000
	FSRS	0.598			
	ISS	0.798			
	LRP	0.757			
	IISR	0.55			
	MSR	0.882			
	EP	0.682			
	HWG	0.618			
	IUR	0.587			
	ND	0.882			

GFI = 0.927, CFI = 0.953.
CITC = Correlated Item Total Correlation, KMO = Kaiser- Meyer- Olkin, GFI = Goodness of Fit Index, CFI = Comparative Fit Index.

Table 1
Non-response bias test assessment using independent sample t-test.

					Levene's test for Equality of Variances		*t*-test for equality of Means		
Variables	Response Type	N	Mean	SD	F	Sig.	*t*	df	Sig. (2-tailed)
I5.0	Early	230	4.511	0.432	1.392	0.254	2.126	98.329	0.057
	Late	60	4.016	0.384					
SCP	Early	230	3.865	0.617	1.037	0.301	-1.167	84.433	0.234
	Late	60	3.793	0.528					
SSCP	Early	230	4.621	0.514	0.005	0.954	0.212	93.953	0.573
	Late	60	4.825	0.437					
SCR	Early	230	2.476	1.078	1.624	0.256	0.514	94.131	0.567
	Late	60	2.359	1.063					

determine their validity, given that all constructs exhibit stronger correlations with their own items than with the items of other constructs' items [23] and Byrne [10]).

5.3. SEM analysis and structural modeling

The model depicted in Fig. 1 is streamlined in Fig. 2. It graphically represents the hypothesized connection between variables in a Structural Equation Modeling analysis. According to Hair et al. (1995), having many indicators for a construct is preferable than using a single indicator. Preserved scale items serve as visible indications of the extrinsic latent variables *Industry 5.0 (I5.0), Sustainable Supply Chain Practices (SSCP), Supply Chain Performance (SCP), Supply Chain Risks (SCR)* given that these 4 factors account for the vast majority of constructing a hypothesized link between Industry 5.0 and SSC. Pinpointing through a single endogenous latent variable is impossible.

The model in Fig. 2 was analyzed using Structural Equation Modeling, and all responses were fed into the AMOS software. The statistical significance of the indicator's measurement section of Structural Equation Modeling is also analyzed using the *t*-value, *p*-value, and *r*-value presented in Table 3 and Fig. 2. The indicators are statistically significant if the *t*-value is greater than 2.00 at ($\alpha = 0.05$) and, the p value must be less than 0.05 [88]. This suggests that the constructs are strongly connected statistically. In addition to this, it substantiates the potential of having casual relationships. For the degree of correlation, we adapt the range of correlation coefficient *r*-value suggested in the literature by Evans [22] and the suggested *r*-value above 0.60 have high strength of relationship. In sum, in this study, we consider any hypothesis as non-significant if its t value < 2.00, *p*-value < 0.05 and *r*-value < 0.60.

The correlation coefficient between Industry 5.0 and Sustainable Supply Chain Practices stands at a robust 0.965. This suggests that the constructs are connected to one another statistically. In addition to this, it substantiates the potential of having casual relationships. In the same manner, the relationship between Industry 5.0 and *Supply Chain Performance*, Sustainable Supply Chain Practice and *Supply Chain Performance*, and Sustainable Supply Chain Practices and *Supply Chain Risks* are significant and their *t*-value, *p*-value and *r*- value are above acceptable range. Hence, these 4 hypotheses were accepted. On the other hand, H4 shows an insignificant result (*t*-value $= 1.58 < 2.00$, *p*-value $= 0.394 > 0.05$, *r*-value $= 0.258 < 0.60$). Hence H4 is rejected. This refers that Industry 5.0 significantly impacts Sustainable Supply Chain Practices and improves Supply Chain Performance. The sustainable supply chain due to Industry 5.0 boosts supply chain performance while maintaining the synergy with nature. Sustainable Supply Chain Practices was also able to alleviate the supply chain uncertainties and risks. According to the result obtained from H4, Industry 5.0 may have mitigated some of the risks, but the impact is not as significant as expected.

5.4. Multigroup analysis

Employees were categorized into three age groups: younger employees (between the ages 24–34), middle-aged employees (ranging in age from 35 to 49), and elderly employees (aged 50 or above). Deciding on the boundaries for the age groups presented a bit of a challenge for two reasons: (1) there has been no previous research that has attempted to provide evidence for the category. of employees based on age in order to assess disparities in attitudes regarding the adoption of Industry 5.0 and Sustainable Supply Chain; and (2) no single age-based cut-off value accurately captures a split in these attitudes. Despite these drawbacks, prior studies on the technological divide can offer some direction in terms of age classification based on views regarding technology use. Prior research [58,93] has confirmed the existence of a digital divide between those in the younger age group (24–34 years old) and those in the geriatric age group (above 50 years old). Consequently, the age thresholds of 34 and 50 years old were utilized in this research. Age was found to have a negative moderator effect in the studies. There is a notable distinction between the unconstrained and fully constrained models, as indicated by the Chi-square difference of 49.144 (df = 20, *p*-value <.001). The unconstrained model is accepted. In terms of model fit, there is a considerable difference between the young (24−34) and elderly (>50) employee's groups. The model's fit varies across different age groups, as demonstrated in Tables 4–9.

The multi-group structural equation modeling studies revealed a notable disparity among the younger and old employee groups in terms of model fit. However, no significant difference was found between the younger and middle-aged employee group, as well as the middle-aged and elderly employee group.

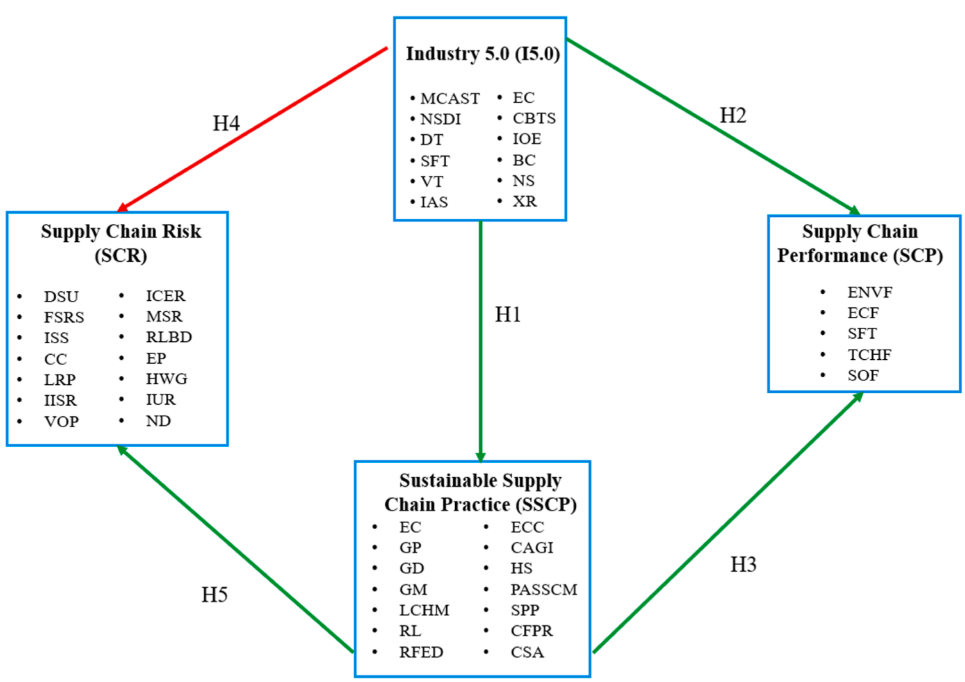

Fig. 1. Proposed hypotheses model.

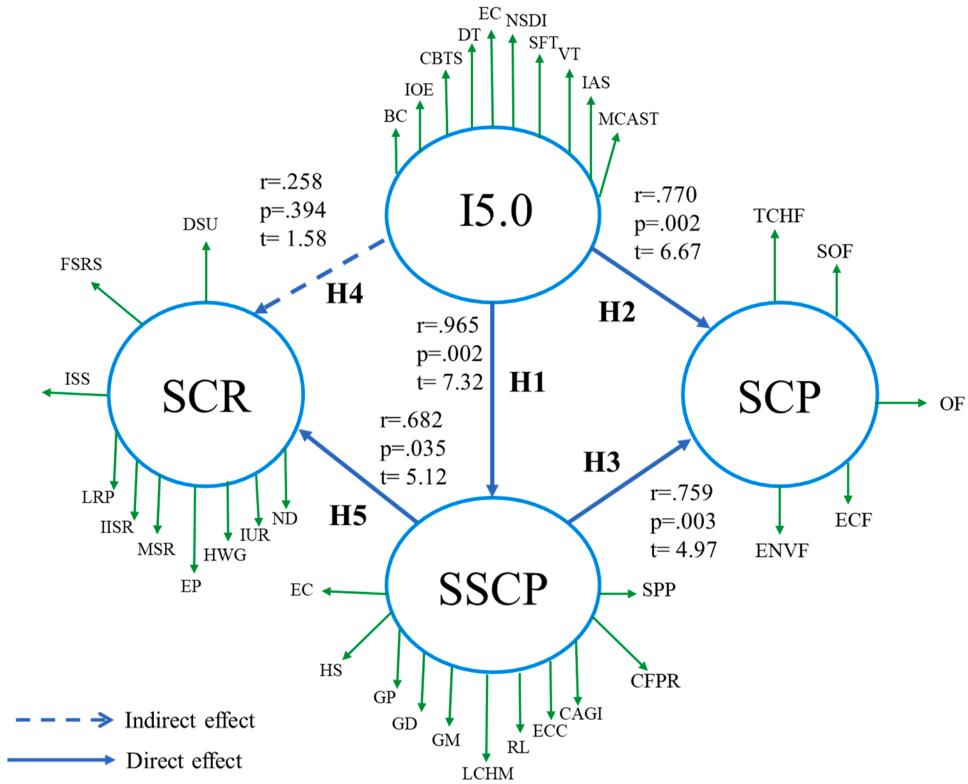

Fig. 2. Examining the result between Industry 5.0, Sustainable Supply Chain Practices, Sustainable Supply Chain Performance, and Supply Chain Risks.

Table 3
Significance analysis of the hypotheses.

	Relationship	t-value	p-value	Significance
H1	I5 to SSCP	7.32	0.002	Yes
H2	I5 to SCP	6.67	0.002	Yes
H3	SSCP to SCP	4.97	0.03	Yes
H4	I5 to SCR	1.58	0.394	No
H5	SSCP to SCR	5.12	0.035	Yes

6. Discussion

This research aimed to bring together the factors associated with Industry 5.0 and sustainable supply chain practices. The aim was to explore the interconnections between these factors and understand how the implementation of both paradigms contributes to improving supply chain performance and minimizing supply chain risks. A survey study was implemented based on 342 responses from industry experts and supply chain professionals from 13 renowned electronics industries in Bangladesh. Their opinions and suggestions were taken into consideration while choosing the factors. A pilot study was done at first, and based on the suggestions, further statistical validation testing was done to establish the model. There were five hypotheses taken into consideration, of which four showed strong relationships and interdependencies between them; one was insignificant; therefore, it was rejected. According to Appendix A and Table 1, 47 factors were considered, 38 were accepted, and 9 were rejected for failing the validation test. The CITC value (> 0.50), Cronbach's alpha value (>0.70) and KMO value (>0.50) justify the result. Further, Table 3 shows the *t*-value and *p*-value between Industry 5.0 to Sustainable Supply Chain Practices, Industry 5.0 to Supply Chain Performance, Sustainable Supply Chain Practices to Supply Chain Performance, Sustainable Supply Chain

Table 5
Model comparison (Younger vs Middle aged): unstrained model.

Model	DF	CMIN	*p*-value	NFI Delta-1	IFI Delta-2	RFI rho-1	TLI rho-2
Structural weights	16	17.218	.239	.012	.013	-.006	-.007

*DF= Degree of Freedom, NFI= Normed Fit Index, IFI= Incremental Fit Index, RFI= Relative Fit Index TLI= Tucker Lewis Index.

Table 6
SEM multiple group analyses: middle aged employee (35–49) and elderly employee (≥ 50).

Model	AIC	CFI	RMR	GFI	RMSEA	PCLOSE
Unconstrained	271.085	0.848	0.051	0.860	0.029	0.898
Structural weights	256.166	0.843	0.059	0.855	0.028	0.991

Table 4
SEM multiple group analyses: younger employee (24–34) vs middle aged employee (35–50).

Model	Akaike's information criterion (AIC)	Comparative Fit Index (CFI)	Root Mean Square (RMR)	Goodness of Fit Index (GFI)	Root Mean Square Error of Approximation (RMSEA)	PCLOSE
Unconstrained	271.085	0.846	0.062	0.850	0.026	0.891
Structural weights	256.166	0.845	0.071	0.845	0.024	0.899

Table 7
Model comparison (Middle aged vs Elderly): unstrained model.

Model	DF	CMIN	P	NFI Delta-1	IFI Delta- 2	RFI rho-1	TLI rho-2
Structural weights	16	28.634	.126	.009	.009	-.005	-.005

Table 8
SEM multiple group analyses: Younger employee (24−34) and elderly employee (≥ 50).

Model	AIC	CFI	RMR	GFI	RMSEA	PCLOSE
Unconstrained	309.796	0.848	0.06	0.854	0.03	0.893
Structural weights	299.383	0.845	0.07	0.849	0.028	0.897

Table 9
Model comparison (Younger vs Elderly): unstrained model.

Model	DF	CMIN	P	NFI Delta-1	IFI Delta- 2	RFI rho-1	TLI rho-2
Structural weights	16	22.541	.021	.009	.010	-.007	-.007

Practices to Supply Chain Risks, are respectively 7.32, 6.67, 4.97 and 5.12 which are above the validation range (t ≥ 2.00). From this, we found out that *H1, H2, H3* and *H5* were valid. However, Industry 5.0 to Supply Chain Risks gives a *t*-value of 1.58, which is below the validation range; hence H4 was rejected. Therefore, the result of the structural equation model testing expressly indicates that there is a positive correlation between Industry 5.0 and sustainable supply chain, Industry 5.0 and supply chain performance, sustainable supply chain and supply chain performance, sustainable supply chain practices and supply chain risks; and insignificant relation between Industry 5.0 and supply chain risks. Moreover, p-value was also below 0.05 for H1, H2, H3, H5 and but higher for H4, thus H4 which refers the rejection of H4. So, this gives us a clear conception that the implementation of Industry 5.0 will develop a sustainable supply chain practices, and as a result, it will enhance the supply chain performance. To develop a more resilient supply chain than I4.0, implementing Industry 5.0 technology is not completely enough to mitigate all the associated risks such as reasoning and building trust and unprecedented disasters. By enabling real-time monitoring and optimization of resource consumption, Industry 5.0 can help mitigating the risk of inefficient resource use and elevate overall efficiency. On the other hand, rapid response to quality issues or customer complaints and by providing transparency and accountability throughout the supply chain, it can also help mitigate the risk of a reduction in market share as well as a loss of reputation. The implementation of SSCM practices and the technologies of Embracing Industry 5.0 necessitates a substantial commitment of both time and resources, and it may also necessitate changes to existing business models and processes. In addition, the execution of new practices or technologies may be accompanied by risks that were not anticipated. Before materializing any new procedures or technologies into place, it is essential to thoroughly analyze the potential risks and the benefits they may bring.

7. Implication of the Study

The study adds to the theoretical comprehension of the connections between Industry 5.0 innovations, sustainable supply chain practices, supply chain performance, and risks.By employing Structural Equation Modeling (SEM), it illuminates the interplay and dependencies among these constructs in the realm of supply chain management, offering insights into their complex interactions. It establishes a robust theoretical framework that integrates Industry 5.0 concepts with sustainable supply chain practices and performance while considering the associated risks. This framework provides a structured foundation for subsequent research and theoretical advancement in understanding the dynamics of modern industrial innovations and sustainable supply chain operations. Through the application of structural equation modeling, the study validates or refines existing theories in the domain of Industry 5.0, sustainable supply chain practices, performance, and risk management. It offers empirical evidence to support, modify, or expand upon established theoretical constructs in the field, contributing to the evolution of these theories.

In terms of practical implication, the outcomes of this study provide practical insights applicable to industry professionals., enabling them to make informed strategic decisions concerning the integration of Industry 5.0 innovations into their supply chain practices. Understanding the relationships between these constructs assists in optimizing operations and mitigating risks while enhancing sustainability performance. Moreover, practical implications include guidelines for identifying, evaluating, and mitigating supply chain risks associated with the adoption of Industry 5.0 innovations. This aids organizations in developing proactive risk mitigation strategies, thereby strengthening the resilience and adaptability of their supply chains. In addition, the study provides practical guidance for enhancing sustainability performance through the adoption of specific Industry 5.0 innovations aligned with sustainable supply chain practices. This knowledge empowers companies to implement environmentally friendly and socially responsible initiatives while improving their operational efficiency.

8. Conclusion and future scope

The objective of this study was to establish an interdependent relationship between the implementation of Industry 5.0 and the practice of sustainable supply chain management. The study commences with a brief history of the industrial revolution, focusing on its progression through the years and analyzing how technological advances have influenced the general direction of specific industries. From mass production to mass customization while also taking into consideration the viability of the world's ecosystems and resources. The findings of this research project provide us with inferences and insights into how the Fifth Industrial Revolution is instigating novel transformations in the business world. The result analysis of the improvised model demonstrates the interdependencies among the associated factors and how they are interrelated with one another.

For structural equation modeling, the models must be built with valid and reliable measures. Future research can focus on making and screening more measurement items for Industry 5.0 and sustainable supply chain management strategies to ensure the models are accurate and reliable. Examining how Industry 5.0 affects sustainable supply chain management: Future research can take a glance at how Industry 5.0 tends to affect sustainable supply chain management, including how it affects environmental and social performance, social conscience, and macroeconomic factors, the influence of environmental regulatory requirements, engagement with stakeholders, organizational culture, the role of user acceptance, and human-technology interaction. structural equation modeling can be used to start figuring out how Industry 5.0 could influence these multiple environments and look for ways to make supply chain management quite sustainable. Overall, using structural equation modeling to construct a connection between Industry 5.0 and sustainable supply chain management can provide valuable information regarding how these thoughts operate and how participants can be enhanced to make them more sustainable by assessing more multi-dimensional qualitative and quantitative factors.

This study is not beyond limitation. Although the Industry 5.0 operational procedure is more or less the same across geographical borders, survey responses pertaining to this study may vary across borders. Thus, generalizing findings from a questionnaire administered to the participants in the Industry 5.0 electronic industry in Bangladesh to other countries necessitates a cautious and systematic approach.

Firstly, it's essential to acknowledge the contextual limitations inherent in the specific setting of Bangladesh and its unique socio-economic, cultural, and industrial landscape. To facilitate generalization, a comparative analysis could be conducted, highlighting similarities and differences between the Bangladesh scenario and those of other countries. Additionally, employing diverse sampling strategies across multiple countries within the Industry 5.0 electronic industry can broaden the scope of representation and aid in extrapolating findings to a more global context. Rigorous statistical techniques and cross-country validations may be employed to ensure the robustness and transferability of the research outcomes. Addressing variations in regulations, market dynamics, and technological infrastructures among different countries is essential to elucidate the extent of the generalizability of the study's findings beyond Bangladesh.

CRediT authorship contribution statement

Md. Asfaq Jamil: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft. **Ridwan Mustofa:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Supervision, Validation. **Niamat Ullah Ibne Hossain:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **S M Atikur Rahman:** Investigation, Resources, Validation, Writing – review & editing. **Dr. Sudipta Chowdhury:** Investigation, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

Authors do not have any conflict of interest for above titled manuscript.

Appendix A

Factors	Subfactors	Description	References
Industry 5.0 Innovation	Machine Cognition and Advance Sensing Technology	Computer vision, Deep learning and GPU computation	Nahavandi [67], [80], [60]
	Networked Sensor Data Interoperability	Framework for integrating heterogeneous sensor network data	Ordieres-Meré et al., [73], [32], (Shahbazi et al., 2020)
	Digital Twin	A real-time data-driven simulation of a physical object, system, or process	Wang et al., [100], (Modoni et al., 2023)
	Shop floor Tracker	Software for real-time shop floor production tracking	Singh et al., [92], [57]
	Virtual Training	Training and education in virtual or simulated environments	Brunzini et al., [9]
	Intelligent Autonomous System	A system that can decide and act without human intervention	Chen et al., [14], [12],
	Edge Computing	Distributed computing paradigm that processes data and computes at or near the network's edge, where data is generated or consumed.	Maddikunta [59]
	Cobots	Robots that can work in collaboration with humans.	Pizoń, Gola [76]
	Internet of Everything	An expansion of the IoT to include people, processes, and data. It envisions a future where everything—physical objects, people, and processes	Leng [54], [12],
	Blockchain	Distributed data ledger, secure, tamper-evident digital ledger. Thus, it is a distributed database with a growing collection of cryptographically protected blocks.	Yadav [105], [98]
	Network Slicing	Method for creating multiple virtual networks or "slices" within a physical network infrastructure. Each network slice is tailored to a use case, such as low-latency, high-bandwidth, or security.	Chi et al., [15], [107]
	Extended Reality	An umbrella term for immersive and interactive digital technologies like VR, AR, and mixed reality (MR). These innovations create an immersive, interactive computer-generated environment that blends the physical and digital worlds.	Koroglu [49], [63]
Sustainable Supply Chain Practice	Energy Consumption	Refers to the energy used to make, transport, and distribute products and services in a supply chain and its ecological effect. Sustainable supply chain management reduces energy use and environmental impact while meeting customer needs and ensuring profitability.	Redchuk et al., [83], [25]
	Green Purchasing	Refers to buying environmentally friendly products. This includes products made from eco-friendly materials, have a lower carbon footprint, and are more energy- or water-efficient.	ZengiN [108]
	Green Design	Refers to designing environmentally friendly products, buildings, and systems. It involves designing a product or system from raw material extraction to disposal to maximize resource efficiency, minimize waste and emissions, and promote renewable energy and materials.	(Yin et al., 2022), [39]
	Green Manufacturing	Sustainable manufacturing methods. Green manufacturing reduces pollution, waste, and inefficiency while promoting sustainability.	(Draghici et al., 2022), [56]
	Less Consumption of Hazardous Material	This factor reduces hazardous materials used in supply chain production, transportation, and distribution.	Oláh et al., [72]
	Reverse Logistics	Refers to overseeing the movement of goods and materials from the consumer back to the original manufacturer or distributor. Reverse logistics maximizes product value and reduces waste.	Sun et al., [96]
	Reduction of fine for environmental disaster	Refers to the reduction of cost which an organization faces due to the natural disaster	Raut [82],[18]
	Environmental Collaboration with Customer	Refers to working with customers to encourage sustainable and eco-friendly practices throughout the supply chain.	Mishra et al., [61]
	Customer Awareness to Green Initiation	This raises customer awareness and participation in green initiatives. This factor encourages customers to be more environmentally friendly and sustainable.	Habib et al., [33]

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Factors	Subfactors	Description	References
	Health and Safety	Health and safety measures protect workers' physical, mental, and emotional health. This prevents workplace accidents, injuries, and illnesses and promotes a secure and healthful work environment.	Golgeci [29]
	Proactive adoption of Sustainable Supply Chain Management	PASSCM is the proactive adoption of sustainable and eco-conciousactions throughout the supply chain.	Bentahar et al., [7]
	Sustainable Procurement Policy	A company's Sustainable Procurement Policy ensures environmentally and socially responsible procurement.	Shooshtarian et al., [91]
	Carbon Foot Print Reduction	Carbon Footprint Reduction reduces an individual or organization's carbon emissions. This reduces carbon emissions from transportation, manufacturing, and energy use.	(Panagiotopoulou et al., 2023)
	Compliance to Social Accountability Standard	Compliance to Social Accountability Standard means following social responsibility guidelines set by various organizations and regulatory bodies.	Yadav [105]
	Contribute to Resource Saving	Reduce waste and conserve natural resources to promote sustainability and environmental protection. Contribute to Resource Saving reduces human impact on nature and finite resource use.	Krishnan et al., [50]
	Well defined Practice for Sustainability Practice	Establishes and implements clear and measurable sustainability practices to promote sustainable development and environmental protection. This provides a transparent, accountable, and effective framework for sustainable practices.	Prasad [77], (Schröder et al., 2023)
Supply Chain Performance	Environmental Factor	Refers any natural or built environmental factor that affects human health, well-being, or quality of life is.	Ghadge [27]
	Economic Factors	Refers to any factor that can impact the economic efficiency of a supply chain. Economic factors = include costs of supply chain, pricing strategies, demand for products and services, economic policies, and global economic conditions.	Sakib et al., [87]
	Operational Factor	This includes production capacity, transportation, inventory management, quality control, and process efficiency.	Lee [53]
	Social Factor	Refers to a business's social and cultural environment, including people's attitudes, beliefs, values, and behaviors. Labor practices, social responsibility, human rights, community involvement, and stakeholder engagement are supply chain management sf.	Rachmawati [79]
	Technological Factor	This is any supply chain management factor associated with technology like Internet of Things, Big Data analytics, blockchain, robotics, automation, and artificial intelligence can be used.	Huang [40]
Supply Chain Risk	Demand and Supply Uncertainty	Supply chain management considers customer demand and supplier capabilities' unpredictability and variability. It is the degree of uncertainty or risk involved in meeting customer demand and managing supplier performance.	Nayeri [69]
	Failure to Select Right Suppliers	Failure to Select Right Suppliers in supply chain management occurs when a company chooses the wrong supplier or partner. Late deliveries, poor materials, and supply chain disruptions can hurt the company's bottom line.	Wu et al., [104]
	Inflexibility of Supply Source	Inflexibility of Supply Source arises in supply chain management when a company relies on one or a few suppliers for critical inputs. Supply disruptions, price volatility, and quality issues can hinder the company's ability to meet customer demand and achieve its business goals.	[2]
	Co-ordination Complexity	Refers to the difficulty of managing and coordinating supply chain network parties. As supply chains become more global and complex, the number of parties involved increases, making it harder to ensure everyone is working toward the same goals. Coordination complexity can cause delays, miscommunication, and other inefficiencies that affect supply chain performance.	Zhong et al., [109]
	Lower Responsiveness Performance	This in supply chain occurs when a company cannot respond quickly to changes in demand or supply due to factors like lack of flexibility, poor communication, long lead times, or supply chain delays.	Bae et al., [5]
	IT & Information Sharing	It means using technology to improve communication, collaboration, and visibility. Information is essential to a successful supply chain in today's business environment, and IISR helps companies streamline operations and improve performance.	Wang, Zhuo [101]
	Volatility of Price	This measures how much prices change in a market or industry over time. Supply and demand, geopolitics, currency fluctuations, and market speculation can cause it.	Tripathi et al., [97]
	Inflation and Currency Exchange Rates (ICER)	Supply chain inflation and currency exchange rates) can be significant. Exchange rates affect goods prices, which affect supply chain profitability. If a company buys raw materials from a foreign supplier and the exchange rate changes, those materials may cost more, raising production costs.	Wei, Xie [103]
	Market Share Reduction	It can affect a company's supply chain by decreasing sales, resulting in excess inventory, lower production and distribution volumes, and cost-cutting.	Villoria et al., [99]
	Reputation Loss and Brand Damage	Refers to supply chain issues that damage brand reputation and image. Quality issues, product recalls, ethical or social concerns, and environmental issues can cause this.	Fracarolli Nunes et al., [24]
	Environmental Pollution	Refers to the environmental damage caused by manufacturing, transportation, and distribution. This pollution includes air, water, waste, and greenhouse gas emissions.	ElFar et al., [21]
	Hazardous Waste Generation	Refers to the production of hazardous waste. Hazardous waste can come from factories, farms, hospitals, and homes. Solvents, pesticides, batteries, electronics, and medical waste are hazardous.	Javaid et al., [44]
	Inefficient Use of Resources	Inefficient Use of Resources (IUR) is a supply chain's wasteful use of energy, water, and raw materials. This may result from inefficient processes, overproduction, or	Helm et al., [35]

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Factors	Subfactors	Description	References
		other factors. IUR increases costs, reduces profitability, and harms the environment.	
	Natural Disaster	Natural disasters like hurricanes, earthquakes, floods, and wildfires can disrupt the supply chain. Natural Disaster can damage infrastructure, property, and transportation, halting goods and services. Natural disasters cause deaths, injuries, and environmental damage.	Sukmono, Junaedi [95]

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