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Unlocking Sustainability's Potential. Revolutionizing Supply Chains Through Blockchain, Forgoing A Greener Path Form Procurement To Delivery

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Abstract
In this era of globalization, supply chain management approaches must prioritize the use of technology while also addressing environmental challenges. In this research, we look at how blockchain technology (BT) might help with sustainable and environmentally friendly supply practices throughout different stages of SCM. More research needs to be conducted that examines green supply chains in detail for environmental performance, particularly about BT, and this study will help to fill that need. A company's environmental performance and the impact of BT on several green supply chain phases are the foci of this research. A further important objective of the project is to examine the effects on the environmental performance of the various links in the green supply chain. This study uses a PLS-based structural equation modeling approach to explore the linkages between BT adoption and green supply chain practices being implemented in stages. Employees of medium-sized manufacturing enterprises in India provided the data. The findings demonstrate that green supply chain management practices and blockchain technology adoption lead to better environmental performance. The study also highlights the multifaceted influence of blockchain on ecological performance by showing a positive association between various phases of the green supply chain and its integration. According to the findings, sustainable supply chain practices and improved performance may be within reach with the support of BT.

Keywords: Digital technologies, Green supply chain management, Environmental performance, PLS, structural equation modeling, Blockchain

1. Introduction

Due to the increased complexity of both the forward and reverse supply chain procedures brought about by the increased geographical separation of the focal firms, suppliers, and customers in the era of global supply chains (Saberi, Kouhizadeh, Sarkis, & Shen, 2019). Technology plays a significant role in the dramatic shifts in supply chain management due to growing environmental consciousness. The increasing prevalence of digital commerce has made incorporating state-of-the-art technology a potent catalyst for enhancing supply chain processes, with far-reaching consequences for ecological preservation. The problems get more intricate when supply chains constantly strive to evaluate green practices and want transparency across phases. According to (S. A. R. Khan et al., 2021), there are growing concerns about visibility in traceability, transparency, and tracking as the number of tiers, intermediates, and marketplaces in supply chains continues to grow. (Mubarik, Raja Mohd Rasi, Mubarak, & Ashraf, 2021) define green practices in the supply chain as collaborative problem-solving and environmental monitoring across all stages and involving several organizations. Strategies for GSCM, including environmentally friendly manufacturing, shipping, and procurement. To guarantee ecologically friendly practices, stakeholders throughout the supply chain need a data-driven method to track and oversee operations (Kouhizadeh, Saberi, & Sarkis, 2021).

According to a 2021 study by Deloitte, the key obstacles to sustainability-driven competitive advantage are supply chain partner isolation and unconnected and disjointed systems. The model fosters data-driven, integrated, end-to-end, stage-by-stage collaboration across all actors in the value chain to build a sustainable footprint that provides measurable sustainability outcomes. Stakeholders also expressed concerns regarding the appropriateness of the data supplied to them. In their 2018 study, Carroll et al. highlighted how important it is to present sustainability data ethically and how some companies may falsify or conceal data to look better than they are. You may find these companies all along the global supply chain. Accordingly, transparent, accurate data becomes crucial in an eco-friendly supply chain. Systems built on the blockchain that forbid administrators or users from erasing, changing, or otherwise tampering with actual data have been emphasized by (Esmaeilian, Sarkis, Lewis, & Behdad, 2020). Several industries, including manufacturing, services, public administration, and finance, have discussed the potential of this system to address stakeholders' worries about the accuracy and visualization of data.

Because a single unsustainable step in the supply chain can make the entire chain unsustainable, each phase must be carefully managed. As a result, a platform for the inter-organizational exchange of information based on blockchain is crucial for the systematic evaluation of green supply chain activities. Stage-wise evaluation has been disregarded in earlier supply chain literature, and only a few studies have touched on stage-wise supply chain management. For example, working with the garment industry as a case study, (Gu et al., 2022) evaluated supply chain responsiveness in stages, with logistical, downstream, and supplier responsiveness as critical elements at each level. According to (Munir et al., 2022), there are three stages of supply chain mapping: upstream, midstream, and downstream. But all that matters are the goals and scope of the investigation. Research assessing the green supply chain strategies in their stages is scarce. Until now, research assessing environmentally friendly practices throughout the supply chain has ignored essential details. An example of external cooperation would include upstream, midstream, or downstream partners; internal operations would be considered internal practices; and (Yousefi & Tosarkani, 2022) would have looked at how both green processes affected green performance. However, the actual image of stage-by-stage performance is limited because they have yet to evaluate the consequences of each stage independently or overall through external green collaboration. (Elhidaoui, Benhida, El Fezazi, Kota, & Lamalem, 2022) integrated upstream, midstream, and downstream mapping into one design to study how supply chain mapping affects sustainable performance. The overall performance is provided, but the impact of each stage-by-stage mapping on long-term performance remains to be determined. To fill this void, the present research views the green supply chain as an integrated whole, with each stage contributing to the previous ones.

Academics are now looking to digital technologies as a possible solution to the problems caused by complex supply networks. (Tan, Wang, Liu, Kang, & Costa, 2020) all point to the growing significance of blockchain technology's applications. Specifically, blockchain's storage, security, tracking, tracing, and promotion of supply chain transparency capabilities have contributed to its rising importance. Despite the increasing fascination with digital technology, microscopic study has examined how Blockchain Technology (BT) impacts environmental performance throughout the many stages and processes of the supply chain. For instance, (Y. Wang, Yang, Qin, Yang, & Li, 2023) assessed the effects of BT on specific areas, such as environmentally friendly production, environmentally friendly architecture, and environmentally friendly transportation and how these elements influenced overall environmental performance. Their study did not quantify the direct impact of BT on ecological performance. Being restricted to the production, transportation, and reverse logistics phases, it only offered a partial picture of the stage-by-stage logistics or supply chain viewpoint. Similarly, (Park & Li, 2021) evaluated the impact of BT adoption on low-carbon performance; however, they neglected to consider environmental performance and instead focused on a single aspect. According to (Paliwal, Chandra, & Sharma, 2020), when applied broadly, the term "environmental performance" encompasses evaluating several environmentally friendly approaches and innovations that help the planet.

In continue discussions on the digital age's supply chain technology applications, it is necessary to fill the gaps highlighted by the study. To begin, there needs to be moreover literature on integrated blockchain research into particular stages of the supply chain that methodically assess sustainability and green practices. There needs to be more in-depth understanding of supply chain processes in the existing literature because most studies either broadly view supply networks or focus on individual steps. The second issue is the absenceneed for more research evaluating the impact of BT on the company's environmental performance. The current state of supply chain blockchain research primarily deals with sustainability in general or environmental challenges in a roundabout way. Thirdly, research on the effects of green supply chains on ecological performance at different stages is lacking. Most recently published works focus on the green supply chain broadly, without delving into the specifics of each step to provide a more comprehensive analysis. This study aims to address these knowledge gaps by investigating the following questions.

RQ1: At what points in the green supply chain does BT have an effect?
RQ2: How does the company's environmental performance change at various points in the green supply chain?
RQ3: How does BT affect the company's sustainability efforts?
Solving these research difficulties would be a significant contribution of our work to numerous vital sectors. The intricate relationship between Blockchain Technology (BT) and GSCM methods is the primary focus of our research. More knowledge about supply chain management would be gained from this, as it would shed light on how emerging technology impacts sustainable practices. Second, the study's findings would shed light on the ways in which BT adoption impacts the environmental performance of businesses. In light of growing environmental concerns and the demand for more sustainable practices from businesses, this data is crucial. Thirdly, the strategic implications of BT integration in the supply chain may be better understood with the help of our study's findings. Businesses would do well to consider how BT might enhance green supply chain operations when formulating strategies to improve their environmental performance. Concerning the fourth point, our research can aid lawmakers and regulatory bodies in crafting more knowledgeable laws concerning the incorporation of BT and sustainable supply chain practices. In addition, our research may offer practical recommendations to enterprises by highlighting the benefits of BT in supply chain processes for the enhancement of environmental performance. Last but not least, this has the potential to lead to more effective laws that promote ecologically conscious business practices. Companies can use this data to make educated decisions about their sustainability and technology budgets.

2. Theoretical underpinning

(Nayak & Dhaigude, 2019) model for the adoption of blockchain technology is the basis for the present investigation. The approach combines resource- and knowledge-based viewpoints to assess the impact of blockchain adoption on the long-term performance of the company. A business may adapt to its dynamic environment and stay ahead of the competition by utilizing its resources and skills according to the resource-based view. (Rane, Thakker, & Kant, 2021) agree that a company's key resources and competencies can provide a lasting competitive advantage because of their intrinsic attributes of being valuable, uncommon, unique, and non-substitutable. Scarcity, in this context, means that resources are not evenly distributed among competitors; valued resources, on the other hand, are those that may both reduce risks and maximize opportunities. Another one can't substitute the resources because they are non-substitutable, and they can't be copied since they are imitable (Kshetri, 2021). The recent surge in sustainability and environmental concerns has also led scholars to back the resource-based perspective (Zhang, Li, Yan, Jiang, & Wei, 2019) in their analyses. The primary emphasis of the resource-based perspective is on in-house and non-transferable assets. The resource-based view has been expanded by the natural resource-based approach, which emphasizes the connection between the organization and its natural surroundings. According to (Almutairi et al., 2023), the resource-based view should prioritize competitive advantage by incorporating tactics such as pollution avoidance, product stewardship, and sustainable development into an all-encompassing sustainability framework. Other authors have also highlighted the importance of openness, stakeholder integration, and collaboration. An extension of the resource-based perspective, the knowledge-based view holds that an organization's most important strategic asset is its specialized human capital's unique and immutable body of knowledge. The model also includes the UTAUT model, which is a theory that attempts to analyze the consequences of embracing new technologies.

3. Literature review and hypotheses development

(Feng, Lai, & Zhu, 2022) state that a supply chain is a network of separate companies that are involved in the transportation of goods, services, capital, and data from their point of origin to the end user. Despite its interconnected nature, the supply chain is considered a single entity for the purposes of calculating profits, losses, and other metrics (Manupati et al., 2020). Supply chains benefit from an emphasis on eco-friendly preservation practices in several ways. One is that it encourages associated businesses to create sustainable products and services, and another is that it strengthens their financial position, making them more competitive in the long run. From waste treatment and recycling all the way through design, production, sales, and procurement, the concept of a green supply chain stresses the importance of greening the supply chain at every step (Sahoo et al., 2022).
Consequently, GSCM shouldn't be limited to just one company; it should encompass the integrated supply chain framework's stage-specific adoption of green practices. From a step-by-step view, GSCM may be described as eco-friendly supply chain management techniques and interactions that contain a green component at every stage of the supply chain (Gawusu et al., 2022). Supply chain will typically have the following three stages: distribution, internal operations, and purchase. For this reason, decision-makers necessitate supply chain visualization for the purpose of assessing the green practices. Earlier studies have broken down the whole supply chain into three distinct phases. According to (Khanfar, Iranmanesh, Ghobakhloo, Senali, & Fathi, 2021), the downstream supply

chain is responsible for facilitating the movement of products, services, and data to end users. Suppliers and sub-suppliers at different levels make up what is called the upstream supply chain. All the processes and procedures that lead to the final goods and services for consumers are part of the midstream supply chain. Because it is an intricate, interconnected web of varied streams, the supply chain's overall green reputation is vulnerable to flaws at any stage. However, in a normal supply chain, the central firm might have little control over all of the suppliers and sub-suppliers. As a result, complex technological integration is required to resolve the ubiquitous problems of information security, transparency, and traceability. Much prior work has used a number of theoretical frameworks to investigate green supply chain literature and blockchain technology. For example, (S. A. Khan et al., 2022) used practice-based theory (PBV) to understand blockchain technology for sustainable development in their study. By integrating resource dependence theory with transaction cost theory, (Bag, Viktorovich, Sahu, & Sahu, 2020) explored how BT adoption could enhance green supply chain integration. To determine the impact of BT adoption on supply chain performance, (Ghahremani-Nahr, Aliahmadi, & Nozari, 2022) applied network theory to their research.

3.1. BT and stage-wise GSCM

In the past, researchers would meticulously map out supply networks to better identify and prevent supply chain management issues. In order to track upstream, downstream, and process value chains using state-of-the-art technology, stage-wise mapping has been investigated by (Rejeb & Rejeb, 2020) as a process-based capacity. (Xu, Zhang, Dou, & Yu, 2023) conducted an investigation into sustainability utilizing an approach that involved stage-wise supply chain mapping. The impact of blockchain technology on supply chain mapping and the subsequent effects on sustainability outcomes were also assessed in this comprehensive review.

Similarly, (Fernandez-Vazquez, Rosillo, De la Fuente, & Puente, 2022) dissected the supply chain into its three constituent parts—logistics, downstream, and upstream to investigate responsiveness at each level. We found that previous studies have shown that a stage-wise evaluation of blockchain technology's impact on the green supply chain and its overall environmental performance is necessary in light of our findings. An integral part of the green supply chain framework, as outlined by (C. Bai & Sarkis, 2020), is the practice of sourcing products, resources, and services in an environmentally conscious manner. This method provides a comprehensive understanding of how blockchain technology integrates with different stages of the supply chain to support sustainable and environmentally friendly progress. The practical implications of this are significant. Decisions that affect society and the environment are a part of green upstream supply chain management. Effective management has the potential to lessen waste while simultaneously improving resource efficiency and corporate procedures (Q. Li, Ma, Shi, & Zhu, 2022). Using blockchain technology in the upstream supply chain to trace a product from its raw material origins to its final consumption location, as well as following recycling and reuse activities. Precise process visibility and control are made possible by extensive tracking from an upstream point.

In addition, (Umar, Khan, Yusoff Yusliza, Ali, & Yu, 2022) have discussed some blockchain-based applications in the environmentally conscious upstream supply chain. Green packaging and logistics data tracking, energy consumption and waste management metrics, supplier performance measurements, development investment metrics, and data storage and analysis are all part of this. Blockchain is essential in greening the upstream supply chain because it brings suppliers together to carefully establish common environmental goals, share risks and responsibilities, reduce ecological effects, and solve different sustainability issues. Therefore, the following hypothesis is put out by the investigation.

H1a: The green upstream SCM is improved via BT integration.

Blockchain technology is really useful since it allows for the internal integration of operations that take place in the middle of the supply chain. This connectivity allows for real-time access to critical data, which is essential for closely tracking and monitoring personnel, financial, and inventory information. According to (Guo, Sun, & Lam, 2020), internal integration is very important in the middle stage. It is foundational in breaking down functional barriers and putting an emphasis on cross-departmental cooperation to satisfy customers' demands better. They found that the company's internal processes significantly improved its environmental performance and competitiveness. (Varriale, Cammarano, Michelino, & Caputo, 2020) has also painstakingly mapped the midstream supply chain operations, which comprise activities like monitoring, process identification, visualizing, and real-time information exchange, as well as inventory tracking. The incorporation of technology like blockchain substantially enhances their capabilities, which are already capable of meeting these needs. Blockchain can precisely monitor green practices by tracking transactions, investments, compensations, and remunerations that are necessary for the supply chain to be in line with ecologically sustainable practices (Hong & Hales, 2021). In light of these illuminating findings and grounded on the standards of academic rigor, our research advances the following hypothesis using this large corpus of information.

H1b: The green midstream SCM is improved with BT integration.

From upstream operations to operational tasks and the downstream supply chain, BT is an integral part of it all. Greening the downstream supply chain is a complex process involving several local and worldwide networks of merchants and distributors at different levels. The benefits of BT integration for greening the downstream supply chain include end-to-end visibility, flexibility, implied confidence, and control over operations, among others. Easy tracking, reduced operating expenses and time, and improved confidence between the supply chain's horizontal and vertical partners are all possible outcomes of these benefits (Mangla, Kazançoğlu, Yıldızbaşı, Öztürk, & Çalık, 2022). (Han & Rani, 2022) asserts that BT can achieve the sustainability and environmental friendliness required to fulfill the downstream supply chain's objectives of reliability, speed, affordability, and flexibility. In a blockchain-based green downstream supply chain, the primary emphasis is on coordinating environmental objectives, risks, and repercussions with downstream clients, customers, and partners. Thus, the research contends.

H1c: The green downstream SCM is improved via BT integration.

3.2. Stage-wise green supply chain and environmental performance

As one builds upon a large body of literature, several significant findings become clear. (Y. Li, Lim, & Wang, 2022) have brought attention to the effects of green supply chain methods, which include collaborative sustainability efforts with supply chain partners and environmentally friendly procurement strategies. They provide empirical evidence that shows how effective internal environmental management approaches are for improving a company's overall environmental performance. Importantly, statistical significance was found for these hypothesized connections. In addition, (F. T. Sunmola, 2021) have provided clarity on the need to green the supply chain by firmly establishing it within the framework of Sustainable Supply Chain Management (SCM). Their findings indicate a positive relationship between environmental performance and the use of green supply chain practices throughout the supply chain. They provided evidence that green procurement practices improve ecological consequences, which is noteworthy. In light of these ground-breaking contributions to the field, our study proposes the following theories, which are supported by these perceptive observations and grounded in thorough academic analysis.

H2a: An environmentally conscious upstream supply chain helps a company do better in the long run.

H2b: The Company's environmental performance is improved by using a Green Midstream supply chain.

H2c: Improve your company's impact on the environment with a Green Downstream supply chain.

3.3. BT and environmental performance

Environmental performance can be enhanced by BT's surveillance and restriction of harmful emissions and pollutants, which enables disintermediation, security, and the inability to manipulate information (Di Vaio & Varriale, 2020). Blockchain technology is able to control and manage energy consumption since it can adequately monitor it in real time. Digital technology can help improve this efficiency even more. According to (M. Wang, Wang, & Abareshi, 2020), blockchain technology has the potential to enhance energy tracing due to its immutability, authenticity, and real-time transactions. So, BT can make a big difference in the way the corporation handles environmental issues. This study found that BT can improve environmental performance in the following ways: by reducing hazardous waste and air emissions, by increasing compliance with environmental regulations, and by encouraging the purchase of ecologically friendly materials and products. As a result, our investigation has led us to the following hypothesis.

H3: The firm's environmental performance is positively enhanced by the integration of BT.

4. Methodology

4.1. *Sampling and data collection*

Indian manufacturing enterprises of a medium size were the subjects of the study. Through the use of survey questions, the proposed conceptual model was evaluated and tested. The researchers distributed the surveys during in-person visits to the industrial sites in five major Indian cities: Delhi, Ludhiana, Indore, Varanasi, and Samba. Respondents in India's manufacturing sector often disregard surveys sent via social media or email. So, in-person visits were conducted to guarantee that the target population was reached. The majority of respondents filled out the surveys immediately in the presence of the researchers, although a small number requested that they be returned in a few days. The study aimed for a diverse range of responses by including participants from various industries in its sample. Textiles, electronics, automobiles, cement, paper, steel, and pharmaceuticals were among the many sectors from which the data was collected. The study has considered data from several industries to offer a more thorough and generalized view of emerging economies, even if BT penetration varies between industrial sectors. There has been a slow start to the deployment of BT in key areas such as manufacturing. Ghode et al. (2020) argues that supply networks should use blockchain technology for improved transparency and efficiency. The market for blockchain adoption across all industries is projected to reach

$28,248.7 million by 2025 from $583.5 million in 2018, according to statistical data. This is a compound annual growth rate of 74.1%. (Research with a capital M, 2018). Accordingly, the study has considered integrating multiple sectors for a varied response rather than concentrating on a single area alone.

This research follows the methodology proposed by (F. Sunmola & Apeji, 2020) due to the nature of our empirical setting, which is the adoption of blockchain technology (BT) in the Indian manufacturing sector, a field where BT is still in its early stages. We were as specific as possible by basing our data on the responses of a single main informant. We also made sure that survey takers were aware of blockchain technology's role in eco-friendly supply chains in accordance with the guidelines proposed by (Y. Bai et al., 2021). By tailoring our methodology to the unique circumstances of BT's early adoption in India's manufacturing sector, we were able to get more accurate and relevant results. In order to ensure that the surveys were filled out accurately, the data needed to do so came from the upper and middle management of these industrial enterprises. Only 357 surveys were sent out, suggesting that many businesses were unable to participate either because of strict internal policies or because they were reluctant to provide data pertaining to the environment. Furthermore, due to the COVID-19 epidemic, several middle and upper-level employees were still working from home, so we were unable to physically visit them. The remaining twenty-two questionnaires were rejected because of an excessive amount of missing data; thus, only 335 were used for the final data analysis. (Nunnally, Knott, Duchnowski, & Parker, 1967) states that the sample size is sufficient for the empirical analysis based on PLS SEM. A minimum of ten times the number of variables used in the study should be included in the sample. Therefore, the current sample size is adequate. Visit https://www.danielsoper.com/statcalc/calculator.aspx?id=89 to use the sample size calculator also plays a role in this study. Furthermore, sufficient sampling is demonstrated by the software. Additionally, we have examined the sampling's appropriateness using the KMO-Bartlett analysis. The results give the acceptable test values for sampling adequacy. The data was gathered from June 2022 to January 2023. Descriptive statistics for the data are provided in Table 1.

Table 1. Respondents Profile (Source: Compiled by authors).

Category	Empty Cell	**Frequency**	**Percentage**
Gender			
Male		204	60.9
Female		131	39.1
Total		335	100
Job title			
Top Management Level	131	39.1	
Middle Management Level	204	60.9	
Total	335	100	

4.2. *Measures*

The research questionnaire scales were adapted from a number of books in order to achieve the study's aims. Modified versions of the primary components used in earlier research (Nozari & Nahr, 2022) were based on stage-wise supply chain mapping. The stage-wise constructs were adjusted and applied to the context of green supply chains in order to assess the environmental performance of BT integration. Each construct scale was developed by adapting preexisting content to the specific research questions. Annexure-I contains a list of the measurement scales that were utilized during the inquiry. The survey questionnaire used in the study was reviewed by four academics in the field of supply chain to ensure the measurement items were valid and appropriate.

Furthermore, the questionnaire was fine-tuned when eight managers from the manufacturing organization provided feedback during its pre-testing. The research analyzed the data using a structural equation modeling strategy based on PLS. According to (Al-Zwainy & Al-Marsomi, 2023), PLS-SEM is a good fit for this study since it can look at correlations between several items that measure the same concept and between multiple factors that can predict a result all at once.

5. Data analysis

5.1. *Exploratory factor analysis*

A satisfactory result of 0.856 was obtained when evaluating the suitability of the sample using the Keyser-Meyer-Olkin (KMO) Measure of sampling adequacy. The data was subsequently subjected to a normality test. All of the observed variables' skewnesses were within the acceptable range of ± 3, and their kurtosises were within the acceptable range of ± 1, as per the set requirements. As stated by Kline (2011), The validity of the measuring items was determined by an exploratory factor analysis (EFA). In this approach, the Promax rotation method and Principal Component Analysis (PCA) were utilized to validate the measurement items under examination reliably. The principal component analysis results confirmed the initial hypothesis of a five-element pattern matrix. In addition, there is more than one eigenvalue for each of the five components. Every single item's loading value was higher than the threshold of 0.70. The reliability of the constructs was tested using Cronbach's alpha. Values above 0.70 were considered high, indicating satisfactory internal consistency, and they suggested good reliability scores among the constructs. According to Hair et al. (2014), the constructs were found to have good reliability when the composite reliability scores were more than 0.70, as shown in Table 2. In order to determine if the latent variables were convergent, we calculated their average variance extract (AVE) values. Our model's convergent validity findings were satisfactory. According to (Hair, Hollingsworth, Randolph, & Chong, 2017), the AVE values were greater than the minimum recommended value of 0.50.

Table 2. Reliability and Validity.

Empty Cell	α	CR	AVE	MSV	MaxR(H)	GDSC	BT	GMSC	GUSC	EP
GDSC	0.942	0.964	0.653	0.016	0.941	**0.873**				
BT	0.938	0.939	0.697	0.019	0.937	−0.008	**0.848**			
GMSC	0.951	0.951	0.581	0.012	0.925	0.043	−0.105	**0.874**		
GUSC	0.936	0.956	0.822	0.018	0.949	0.016	0.142	0.084	**0.912**	
EP	0.827	0.826	0.589	0.016	0.874	0.131	−0.006	−0.064	0.015	**0.766**

Note: GDSC = Green Downstream Supply Chain; BT = Blockchain Technology; GMSC = Green Midstream Supply Chain; GUSC = Green upstream supply chain; EP = Environmental Performance; α = Cronbach's alpha; CR = Composite Reliability; AVE = Average Variance Extract; MSV = Minimum Shared Value; MaxR(H) = Maximum Reliability.

The discriminant validity was evaluated using the Fornell-Larcker criterion, which involves ensuring that the construct's AVE value is higher than the other correlation values (Ab Hamid, Sami, & Sidek, 2017). There can be no doubt about the discriminant validity amongst constructs as all of them meet the proposed criteria. Additionally, in order to assess discriminant validity, MaxR(H) values greater than 0.80 were utilized, CR scores greater than AVE scores, and MSV scores lower than AVE ratings (Hu & Bentler, 1999). Because all of the criteria in Table 2 were up to par, we can say that the discriminant validity is good.

5.2. *Bias testing*

Principal component analysis based on Harman's single-factor method was the first step. Our findings indicate that the level of explanation is lower than 50%, in line with (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). Secondly, we followed (Kock, 2015) recommendation and tested for collinearity using the variance inflation factor (VIF). Our research does not involve multi-collinearity because our model's VIF remains below the recommended maximum value of 3.3.

5.3. *Confirmatory factor analysis*

We performed a Confirmatory Factor Analysis (CFA) using the AMOS 24 program following the results of the Exploratory Factor Analysis (EFA). Final model fit indices are well-aligned with the data, according to CFA results for first-order constructs. These indexes contain the following metrics: Results: 0.976 for the Confirmatory Fit Index (CFI), 0.914 for the Goodness of Fit Index (GFI), 0.976 for the Incremental Fit Index (IFI), 0.972 for the Tucker-Lewis Index (TLI), 0.046 for the Root Mean Square Residual (RMR), 0.067 for the Chi-square (CMIN), 374.558 for the Degrees of Freedom (df), and 1.703 for the Chi-square/degrees of freedom (CMIN/df). The concepts being studied now have empirical support thanks to all of these results, which indicate a significant correlation between the provided model and the data.

Taken as a whole, these results indicate a good match between the model and the data, lending credence to the validity of the proposed theoretical framework for explaining the study's findings. Fit scores were considered adequate since the normed CMIN/df value of 1.703 was below the maximum permissible value of 3.0 (Bentler, 1990). An RMSEA of 0.046 and an RMR of 0.067 were considered to be within acceptable ranges. When the CFI, GFI, TLI, and IFI scores were higher than the minimum needed value of 0.90, it meant that the model fit was good (Hu & Bentler, 1999). Therefore, it is safe to say that the data being analyzed fits the model adequately and can be utilized to assess assumptions made in the future.

6. Results

In our work, we utilized Amos version 24's Structural Equation Modeling (SEM) to assess the models and test the assumptions. One reason SEM was chosen was because it can simultaneously assess both direct and indirect impacts. A more precise means of evaluating mediating elements was made available by this approach. In addition, SEM allowed us to take use of the bootstrapping method, which is applicable to a variety of sample sizes and does away with the requirement to assume normalcy. To test the hypothesized effects, we employed the bootstrapping re-sampling method. This comprised 5,000 resamples that were accompanied by 95% confidence intervals that were corrected for bias (Hayes & Scharkow, 2013). The progressive implementation of green supply chain strategies and the pivotal role played by BT were both attributed to this uplift.

The empirical findings demonstrate that the three stages of the green supply chain—upstream, midstream, and downstream—are significantly and positively affected by blockchain integration. An appropriate response to the research questions (RQ) is also provided by the study's conclusions. Part of the focus of RQ1 is to evaluate how BT has affected different parts of the green supply chain. The results address this study question by evaluating the hypothesized relationships in H1a, H1b, and H1c. All signs indicate that BT contributes positively to the environmentally friendly stages of the supply chain, from the beginning to the end. Furthermore, the study's findings significantly tackle RQ2, which is all about figuring out how different parts of the green supply chain affect the company's environmental performance. The results demonstrate a strong and positive relationship between the implementation of green supply chain strategies at each stage and the enhanced environmental performance of manufacturing enterprises in India. All three of these hypotheses (H2a, H2b, and H2c) are compatible with this statement. Also, we did a good job with RQ3, which asked how we can measure the impact of BT on environmental performance. The investigation of BT integration demonstrated a strong and positive correlation with the environmental performance of firms, lending credence to hypothesis H3. When taken as a whole, these studies show that industrial enterprises in India may greatly improve their environmental performance by integrating BT and using green supply chain techniques.

Important policy and decision-makers in green supply chains should take note of the study's findings. The research shows that Indian manufacturing firms can improve their environmental performance by incorporating BT into their green supply chains in a step-by-step approach. The model looked at several associations in the study to find connections between different factors. Table 3 shows the outcomes of the structural model analysis, which relied on covariances for its analysis.

Table 3. Hypotheses Testing.

Hypotheses	Path Relationships			β	T-Values	P Values	Result
H1a	GUSC	<—	BT	0.16	4.424	**	Supported
H1b	GMSC	<—	BT	0.2	3.652	**	Supported
H1c	GDSC	<—	BT	0.3	2.075	*	Supported
H2a	EP	<—	GUSC	0.16	2.416	*	Supported
H2b	EP	<—	GMSC	0.42	4.912	***	Supported
H2c	EP	<—	GDSC	0.18	2.551	**	Supported
H3	EP	<—	BT	0.21	2.476	*	Supported

Note: GDSC = Green Downstream Supply Chain; BT = Blockchain Technology; GMSC = Green Midstream Supply Chain; GUSC = Green upstream supply chain; EP = Environmental Performance; β = Beta Value; * = <0.05; ** = <0.01; *** = <0.001.

7. Discussion

The study's findings support hypotheses H1–H3, demonstrating the significant and beneficial relationships between the use of blockchain technology (BT) in the upstream, midstream, and downstream stages of green supply chains. In addition, these green supply chains that are implemented in stages have a strong association with the environmental performance of businesses. These findings back up earlier research in the field and are in line with it. For instance, our research backs up BT's positive impact on the environmentally friendly upstream supply chain. Consistent with prior research(Tönnissen & Teuteberg, 2020). They have previously covered the ways in which blockchain technology might improve transparency and traceability in the supply chain, particularly in relation to sustainability efforts in the upstream sourcing phase of the chain. Our investigation's findings are validated and applicable within the present literature due to these consistent outcomes.

According to the most current research, BT also benefits the environmentally friendly midstream supply chain. Previous research has shown that BT has a good effect on green manufacturing practices in the middle of the supply chain, and our findings are in line with that. Consistent with the findings of (Z. Khan, Badeeb, & Nawaz, 2022), the results also show that BT has a positive impact on the downstream green supply chain. The benefit of BT on supply chain mapping is detailed in the second study. The study anticipates that BT will positively affect the downstream supply chain mapping as a component of the overall supply chain mapping. Adopting BT becomes an obvious solution for building a green supply chain network at every stage because to its qualities of security, privacy, traceability, transparency, and monitoring (Jasrotia, Rai, Rai, & Giri, 2024). The addition of BT also points to a positive relationship between the company's environmental performance and its incorporation.

By providing strong evidence for the proposed framework and its assumptions, our research also contributes to the existing literature. This empirical confirmation lends credence to the concept that businesses can improve their overall environmental performance by implementing eco-friendly measures all throughout the supply chain.

Specifically, we have shown that two major assumptions are correct. First, including BT at all critical stages—upstream, midstream, and downstream—greatly improves the overall environmental sustainability of the supply chain. Our findings build on and enhance those of previous studies, which indicated how BT improves green supply chain operations, particularly in the production and logistics stages. However, our study adds to these findings by demonstrating that BT supports environmentally friendly supply chain practices throughout the entire process, from procurement upstream to operations midstream and distribution downstream.Furthermore, our study contributes to and bolsters previous research that assesses the positive impacts of green practices on an organization's environmental performance at several phases, including upstream, midstream, and downstream.

8. Limitations and future research directions

Since this research exclusively considers industrial organizations with upper- and middle-level management, it does have some limitations. In order to conduct a more comprehensive analysis, it would be beneficial for future researchers to focus on recruiting samples that encompass all levels of employees from a diverse variety of organizations, including those in the service and industrial sectors. While the study does a better job of covering the green supply chain by zeroing down on the stage-wise constructions, it still only covers environmental performance, which is too limited of a definition of sustainability. But the area may be even better if, within the framework of ecologically friendly upstream, intermediate, and downstream supply chains, a triple bottom line approach was more thoroughly investigated. This approach considers economic, social, and environmental effects. Evaluating the effects of BT is also the exclusive focus of the study. But other industry 4.0 technologies, such as the internet of things, artificial intelligence, and big data analytics, could be better understood if we looked at how these data-driven tools can help companies reduce waste, increase energy efficiency, and improve supply chain visibility. The study's empirical analysis relies on pre-tested scales, but a more comprehensive approach that incorporates mixed methods or qualitative data can provide more insights. Our research suffers from a lack of sector-specific insights due to its incorporation of data from other industries. The study also can't do sector-specific analyses of the suggested associations because of its small sample size. Consequently, our work can be built upon by academics in the future who are interested in doing extensive sector-specific analyses.

8. Conclusion

Digital technologies, particularly those associated with Industry 4.0, have recently attracted a great deal of attention from supply chain management researchers. The utilisation of technologies such as blockchain, AI, big data analytics, and the Internet of Things has the potential to greatly enhance the connectivity and transparency of the supply chain environment. This is the general outline of our research, which builds on previous work by investigating the function of digital technology—more especially, blockchain—in conjunction with GSCM in a developing market like India's. A more thorough, step-by-step study provides a deeper understanding, even though the concept of a "green supply chain" provides useful information. As a result, our study divides the green supply chain into three distinct parts: the upstream, the midstream, and the downstream. When these

GSCM components are integrated into blockchain-based supply chains, we meticulously evaluate their impact on the environmental performance of participating enterprises. Within a comprehensive structural model, the study provides statistical proof of the favourable effects of GSCM on the environmental performance of Indian firms and the expected implications of BT on stage-wise GSCM practices. Importantly, this highlights the following realisation: Indian companies' environmental performance is ultimately improved through efficient BT integration, which in turn strengthens GSCM processes. One of the rare pioneering studies in the industry, our research uses empirical analysis to probe the relationship between digital capabilities and GSCM practices in great detail, all the while keeping a keen eye on environmental sustainability. Our findings help fill in the gaps in our knowledge about how these ever-changing dynamics might facilitate improvements in environmental performance in a developing nation like India's economy through the integration of green supply chain management with digital technologies.

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