THE ROLE OF BLOCKCHAIN TECHNOLOGY IN FOOD SUPPLY CHAINS SUSTAINABILITY

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ABSTRACT

Blockchain technology is increasingly recognized as an optimal solution to address the sustainability challenges in global supply chains, particularly in the food supply sector. However, existing research predominantly focuses on the application of Blockchain in production processes, product traceability, and the implementation of smart contracts, with limited attention given to its role in promoting a sustainable food supply chain. Based on practical experience and theoretical frameworks, this study was conducted to examine and assess the impact of Blockchain technology on the sustainability of the food supply chain. The research employs PLS-SMART software version 4.0 for data analysis. Through a survey of customers, a dataset of 268 valid samples was used for the analysis. The findings of this study provide valuable insights for managers, enabling them to make informed decisions regarding the application of Blockchain technology in business operations. This, in turn, contributes to the development of a sustainable food supply chain that meets market demands and creates a competitive advantage in the marketplace.

Keywords: Blockchain technology, sustainable chain, sustainable food supply chain.

1. INTRODUCTION

In the context of digital transformation, the application of modern technologies by organizations, producers, and businesses across the entire process—from production and business operations to distribution—has contributed to the formation of sustainable supply chains. Particularly, the Covid-19 pandemic in 2020 exposed serious limitations in the current system, as the number of people facing hunger and food insecurity increased amidst a crisis that exacerbated pre-existing inequalities hindering development [1]. The issues of food insecurity, food fraud, poor distribution quality, and food waste have raised significant environmental concerns.

In this context, the food supply chain plays a critical role in connecting local producers with consumers, contributing to sustainable development, supporting local economies, and providing fresh, high-quality products. However, this supply chain system has yet to reach full development due to the disparity between consumer demand and the supply capacity of producers.

Building and implementing a transparent and efficient traceability system for sustainable food supply chains (SSC) is a complex process, primarily due to the diversity

of activities involved and the lack of bidirectional information flow among stakeholders [2]. Moreover, many existing traceability systems only provide information on certain aspects or are only accessible to specific members within the supply chain [3]. These barriers have prompted food producers and other SSC participants to develop new skills and solutions to ensure effective communication and transparency throughout the entire process. In this context, the adoption of advanced technological solutions particularly blockchain technology (BBT)—is seen as a promising approach to enhance transparency and verifiability across the supply chain, while also providing consumers with greater confidence regarding the quality and safety of products [4].

BBT is considered a comprehensive solution to the challenges faced across various industries and supply chains [5], [6]. Previous studies have highlighted the numerous benefits supply chains can derive from adopting blockchain, including enhanced transparency [7], [8], [9], improved business operational efficiency (Gawankar et al., 2020) [6], and business model innovation [10]. Furthermore, in the current digital age BBT is increasingly being applied in the food industry to enhance food security and quality [11]. This technology not only strengthens security but also plays a vital role in improving traceability [1].

To modernize sustainable supply chains, this study focuses on analyzing the impact of BBT on SSC, while also examining the mediating role of green products (GP) and green supply (GS) in this relationship. The factors driving the application of BBT are expected to contribute to achieving sustainable development goals by strengthening sustainable supply chains, fostering green product development, and enhancing green supply capabilities.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1. Literature review

Blockchain Technology

In recent years, several studies have explored the potential of BBT in food supply chains, particularly in the context of the growing interest in sustainable development within the research community. As one of the prominent applications of digital technology, blockchain is regarded as a highly secure data storage method. Adding each new "block" of data to the system requires consensus from all members, thereby ensuring that every transaction is verified transparently and securely.

Wang et al. (2021) [12] emphasize that the peer-to-peer consensus mechanism of BBT makes it extremely difficult for malicious actors to alter data. BBT has been widely recognized by researchers for its potential to enhance transparency, accessibility, and information sharing among stakeholders at various stages of the food supply chain. As a result, BBT plays a vital role in the development of a sustainable supply chain [13], [14].

Moreover, Tiscini et al. (2020) [15] argue that the transparency and verifiability embedded in BBT processes help eliminate the risk of fraud and opportunistic behavior within the supply chain. This contributes to reducing food adulteration and counterfeiting throughout the entire production and distribution process [10]. As a result, supply chain participants are better positioned to market products based on production process

characteristics or product origin [16]. Therefore, BBT effectively responds to the growing demand of consumers for trustworthy and transparent information.

Sustainable Supply Chain

To meet customer expectations, food producers face increasing pressure to ensure on-time delivery of high-quality products while optimizing production and operational costs. The growing trend of outsourcing parts of the supply chain and establishing manufacturing and distribution centers in low-cost regions has significantly increased supply chain complexity. This complexity has, in turn, contributed to higher levels of pollution and global warming. Therefore, minimizing greenhouse gas emissions is a critical factor in mitigating the adverse impacts of climate change and air pollution [17]. The "Net Zero" goal is defined as a balanced state in which the amount of carbon dioxide and other greenhouse gases emitted into the atmosphere is offset by an equivalent amount being absorbed [18]. According to Umar et al. (2020) [19] highlight that technological advancements play a vital role in reducing CO_2 emissions throughout the production and operational stages of the supply chain. In this context, sustainable supply chain management has emerged as a strategic approach aimed at minimizing environmental and social impacts while maximizing economic benefits. A sustainable supply chain integrates the principles of sustainable development across all stages—from raw material extraction, production, transportation, and distribution, to consumption and end-of-life product management.

2.2. Research Hypotheses and Conceptual Model

The decentralized trust mechanism, a fundamental characteristic of blockchain technology, holds substantial potential for improving transparency in supply chains [20]. The immutability of data stored on the blockchain, combined with the network's consensus protocol, effectively prevents unauthorized modifications. This helps to reduce fraud and corruption by ensuring the authenticity of products, particularly in the agricultural sector [21]. Furthermore, blockchain's capacity to foster trust and promote multilateral collaboration among supply chain actors can create a favorable environment for verifying and monitoring activities, thereby supporting sustainable practices [22]. Based on these arguments, the following hypothesis is proposed:

H1: Blockchain technology (BBT) has a positive impact on green product (GP)

BBT enables purchasing companies to gain deep insights into suppliers' operations, including the origin of raw materials, production processes, and transportation activities. This level of transparency is critical for accurately assessing supplier risks and value. For example, firms can use blockchain to verify the sustainability of raw material sourcing from partners. Procurement has been recognized as one of the primary areas of blockchain application, allowing companies to evaluate suppliers based on detailed information about purchasing, production, and logistics activities [23].

By enhancing visibility into transactions among suppliers and other stakeholders, BBT allows companies to track supplier performance and gather essential data to optimize price negotiations. Furthermore, through the integration of smart identification systems and GPS-enabled transportation, BBT makes it possible to monitor the exact quantity, origin, and destination of goods in real time [24]. In addition to establishing a strong and

integrated database, BBT supports business process traceability, secure data sharing, and real-time data analytics. These capabilities enable companies to assess competitive dynamics and forecast market trends, enhancing their responsiveness to market changes [25]. Thus, the following hypothesis H2 is proposed:

H2: Blockchain technology (BBT) has a positive impact on green supply (GS)

In the manufacturing sector, the application of BBT facilitates the activation of automation systems, enabling precise identification and tracking of materials and products. This significantly reduces costs associated with human errors. By embedding intelligence into goods during the production process, blockchain allows not only accurate identification of raw materials and components but also precise measurement of waste generation and incidents. These capabilities enable managers to identify bottlenecks and weaknesses in production workflows [26].

Adams et al. (2022) [27] highlight that an increasing number of companies and researchers are committed to preserving the environment for future generations, and many organizations have recognized the importance of building sustainable supply chains. Core activities within such supply chains include green design, green products, green procurement, green manufacturing, green transportation, and reverse logistics. Therefore, this study proposes the following hypotheses H3 and H4:

H3: Green products (GP) have a positive impact on the sustainable supply chain (SSC).

H4: Green supply (GS) has a positive impact on the sustainable supply chain (SSC)

The complexity of technology has always been an important factor for businesses in general, and food businesses in particular, and it is also a key topic in research on innovation and technology adoption [28], [29]. Current studies indicate that businesses tend to prioritize the adoption of user-friendly technologies that provide practical benefits and create a relatively competitive advantage in the production process [30].

In this context, BBT has emerged as an effective solution for supply chain management in organizations, with the ability to build trust, enhance transparency, and establish consensus among stakeholders, thereby bringing comprehensive benefits and ensuring flexibility in business outcomes. The application potential of Blockchain is not limited to the field of cryptocurrencies but is also recognized as a foundational mechanism capable of significantly improving the efficiency and productivity of supply chains. Logistics operations require a system of complex international regulations to oversee the movement of goods on a global scale. However, due to the existence of information asymmetry in the large volume of data flows, this system poses a risk of errors or corrupt behavior among intermediary parties [31]. The following hypothesis H5 is therefore proposed

H5: Blockchain technology (BBT) has a positive impact on the sustainable supply chain (SSC).

The research model developed by the author is based on relevant theoretical foundations and previous related studies. The author proposes the research model in Figure 1 as follows:
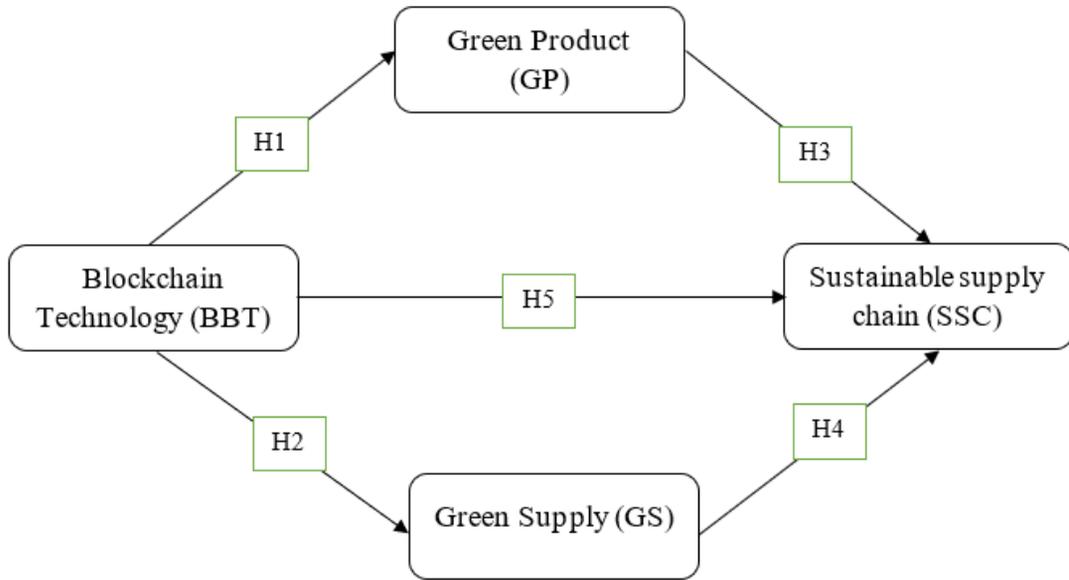
Figure 1. Proposed Research Model

Source: Author (2025)

3. RESEARCH METHODOLOGY

The observed measurement scales in the model are based on a 1-5 Likert scale (5 levels) to design the survey questionnaire. First, the 4 observed measurement scales in the BBT model are measured according to Yadav & Singh (2020) [32] and Angelis & Da Silva (2019) [33]. At the same time, to measure the dependent factor of the sustainable supply chain (SSC) scale with 4 observed variables, the author has inherited the observed scales from Wibowo (2018) [34]. In addition, the Green Supply (GS) scale with 4 observed variables was adjusted by Wang et al. (2020) [35]. Finally, the Green Product (GP) scale with 3 observed variables for each scale was taken from the study by Khan et al. (2022) [36].

This study uses a quantitative research method, with the survey target being managers and employees working in food businesses in Ho Chi Minh City. The collected data is analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) through the SmartPLS version 4.0 software. Additionally, a bootstrap test was conducted to assess the reliability and stability of the relationships in the research model.

4. RESEARCH RESULTS

4.1. Description of the Research Sample

The author conducted a survey with 300 samples over a period of one month using a link sent via email and Google Forms. At the end of the process, 278 responses were collected, accounting for 92.7%. The author filtered the responses and removed invalid questionnaires due to insufficient information. As a result, 268 valid responses were obtained for data analysis. The research sample results are presented by the author in Table 1.

Table 1. Research Sample Statistics

		n	Percent (%)
Gender	Male	145	54.1
	Female	123	45.9
Years old	Under 40	104	38.81
	40-49	98	36.57
	Over 50	66	24.63
Job Position	Staff	126	47.01
	Manager	142	52.99
Eperience	Under 5 years	97	36.19
	5-10 years	109	40.67
	Over 10	62	23.13

(Source: Author's calculations, 2025)

4.2. Measurement model analysis

The quality of the observed variables in the model, after the author removed the observed variable GS4 with an Outer Loadings coefficient < 0.7, is presented in Table 2. The reliability of the scale was confirmed with Cronbach's Alpha > 0.7 and CR > 0.8 (Hair et al., 2019) [37]. The convergent validity was confirmed by AVE values > 0.7. Additionally, all VIF values were less than 3, indicating that there is no multicollinearity in the model [37].

Table 2. Construct reliability and validity

Variables	Factor loading	Cronbach's Alpha	Composite Reliability	Average Variance Extracted - AVE	VIF
BBT	0.823 – 0.865	0.865	0.908	0.712	2.179
GP	0.853 – 0.886	0.833	0.900	0.749	1.792
GS	0.864 – 0.898	0.856	0.913	0.777	1.805
SSC	0.876 - 0.882	0.859	0.905	0.705	2.179

(Source: Author's calculations, 2025)

All HTMT values are less than 0.9, thus ensuring discriminant validity [38]. The results are presented in Table 3.

Table 3. Heterotrait-Monotrait results

	BBT	GP	GS	SSC
BBT				
GP	0.757			
GS	0.752	0.640		
SSC	0.824	0.855	0.787	

(Source: Author's calculations, 2025)

The R² values for the variables GP, GS, and SSC are 0.415, 0.419, and 0.676, respectively, while the adjusted R² values are 0.413, 0.417, and 0.672, all of which are greater than 0.1 (Falk & Miller, 1992) [39], indicating that the model has an adequate and reliable explanatory power.

Additionally, the bootstrap analysis results with 5,000 resamples show that the relationships between the factors in the model are statistically significant. Furthermore, the study also reveals that all p-values obtained are 0, which is lower than the accepted threshold of P-value < 0.05, confirming that all five hypotheses are supported at a 95% confidence level. All original sample values are positive, suggesting that the proposed relationships have a positive impact.

Moreover, the analysis of the mediating role in the SEM model shows that all mediating relationships are statistically significant ($P < 0.05$), with all effect coefficients being positive. This confirms the significant mediating role of the variables in transmitting the impact between the factors in the research model. The results are presented in Table 4 and Figure 2.

Table 4. Boostrapping results

Paths	Hypotheses	Co- efficient	T Statistics	P Values	Result
BBT -> GP	H1	0.644	11.937	0.000	*Accept*
BBT -> GS	H2	0.647	12.169	0.000	*Accept*
GP -> SSC	H3	0.396	7.900	0.000	*Accept*
GS -> SSC	H4	0.286	7.221	0.000	*Accept*
BBT -> SSC	H5	0.273	5.230	0.000	*Accept*

(Source: Author's calculations, 2025)
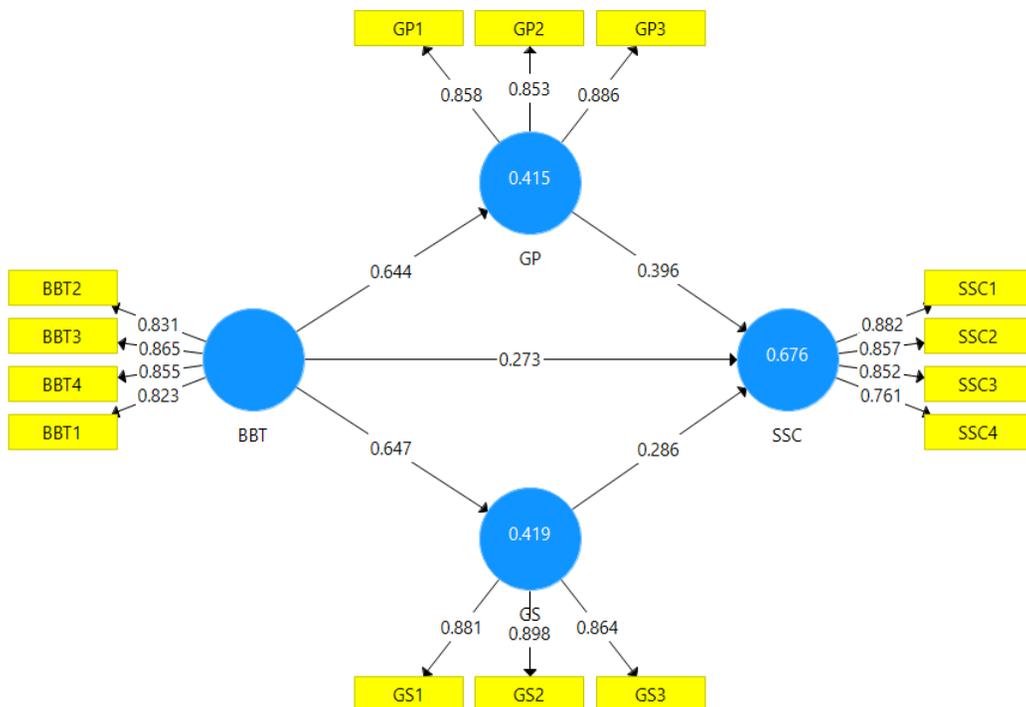
Figure 2. Diagram of SEM analysis result

(Source: Author's calculations, 2025)

5. DISCUSSION OF RESEARCH RESULTS

The positive relationship between Blockchain Technology (BBT) and Green Product (GP) indicates that the application of blockchain technology contributes to the development of green products, while also validating the transparency and traceability of products in the food industry. This supports the research perspective of Tripoli & Schmidhuber (2019) [21], which emphasizes the role of technology in providing green products through the application and development of environmentally friendly technologies in production, transportation of eco-friendly goods, and assessing the sustainability of product

Additionally, green supply (GS) and green products (GP) positively influence the sustainable supply chain (SSC), further supporting the argument that the development of green products can bring value to the sustainable supply chain as well as a competitive advantage for businesses (Al-Abdallah & Al-Salim, 2021) [40].

Moreover, BBT also shows a direct impact on SSC, as mentioned by Yunan & Alam (2020) [30]. However, concerns remain about the cost asymmetry, particularly for small and medium-sized enterprises (SMEs) in the food industry. These businesses are facing the challenge of balancing the investment costs in modern technology with the ability to effectively participate in the overall food supply chain. A feasible strategy is to divide the adoption of BBT into phased implementations over time. Each phase can focus on a specific aspect of the supply chain, such as: starting with raw material traceability, followed by inventory management, and then transportation monitoring (Saberi et al., 2019) [41]. This step-by-step approach not only helps enterprises optimize initial investment costs but also facilitates gradual adaptation to the new technology while minimizing the risks associated with incorrect implementation or complete failure.

6. CONCLUSION

This study provides empirical results to assess the impact of Blockchain technology (BBT) on the sustainable supply chain (SSC), clarifying the direct and indirect roles of BBT through supply chain governance factors such as green supply (GS) and green products (GP). The results indicate that managers in food industry businesses need to quickly adapt to the digital industrial revolution context, while also considering the appropriate allocation of financial resources to implement technology in production and business operations, from green supply to green products, aiming towards the development of a sustainable supply chain.

Clearly, businesses cannot remain outside the digital transformation trend, especially in the food industry—where factors such as traceability, data storage, and transparency are increasingly playing a key role. The adoption of BBT not only allows consumers to easily track and trace product information, thereby enhancing their confidence in consumption, but also helps businesses increase perceived value for customers, attract consumers, and build a sustainable food supply chain.

BBT is no longer a novel technology for businesses in general, and those in the food industry in particular. It has increasingly become more widespread globally. The application of BBT technology helps businesses create a unique impression with customers—a crucial factor in the context of increasingly stringent global food safety and food security requirements. Therefore, businesses need to develop an appropriate strategy for applying BBT technology in production and business activities to strengthen trust from consumers and relevant partners, thereby expanding market share, enhancing competitiveness, and striving for sustainable development.

However, investing in technology—especially advanced technologies like BBT—requires businesses to have a financial resource allocation plan that aligns with their current scale and capabilities. Companies should consider applying BBT in phases, stage by stage, before moving towards full implementation, in order to ensure effectiveness and feasibility in each specific context.

Although the study has achieved certain results in assessing the impact of BBT through green products and green supply on the sustainable supply chain, there are still some limitations. Specifically, the study has not considered other factors such as green design, green training, or human-related factors, which are considered important elements in the supply chain. Additionally, the scope of the study is limited to Ho Chi Minh City with a relatively small sample size. Therefore, future studies should expand the survey scope, increase the sample size, and incorporate additional factors to gain a more comprehensive understanding of the impact of BBT technology on the sustainable supply chain.

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TÓM TẮT

VAI TRÒ CỦA CÔNG NGHỆ BLOCKCHAIN TRONG CHUỖI CUNG ỨNG THỰC PHẨM BỀN VỮNG

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Công nghệ Blockchain đang ngày càng được xem là một công cụ hiệu quả trong việc giải quyết các vấn đề liên quan đến tính bền vững của chuỗi cung ứng toàn cầu, đặc biệt là trong ngành thực phẩm. Mặc dù vậy, phần lớn các nghiên cứu hiện nay mới chỉ dừng lại ở khía cạnh ứng dụng Blockchain vào sản xuất, truy xuất nguồn gốc và hợp đồng thông minh, trong khi vai trò của công nghệ này đối với việc phát triển một chuỗi cung ứng thực phẩm bền vững vẫn còn chưa được nghiên cứu đầy đủ. Trên cơ sở kết hợp giữa lý thuyết và khảo sát thực tiễn, nghiên cứu này được thực hiện nhằm phân tích và đánh giá vai trò của công nghệ Blockchain đến tính bền vững trong chuỗi cung ứng thực phẩm. Dữ liệu khảo sát từ 268 mẫu hợp lệ được xử lý và phân tích bằng phần mềm PLS-SMART 4.0. Kết quả nghiên cứu mang lại những thông tin có giá trị cho các nhà quản trị trong việc đưa ra các quyết định chiến lược liên quan đến ứng dụng Blockchain, từ đó thúc đẩy sự phát triển của chuỗi cung ứng thực phẩm bền vững, đáp ứng nhu cầu thị trường và nâng cao năng lực cạnh tranh cho doanh nghiệp.

Từ khóa: Công nghệ Blockchain, chuỗi cung ứng bền vững, chuỗi cung ứng thực phẩm bền vững.