

Blockchain Implementation Challenges for Sustainable Supply Chains

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Blockchain technology (BT) has attracted a lot of interest and buzz as a revolutionary innovation. Organizations are now thinking about implementing this technology because of its upsides. Cost reductions, improved accountability and traceability, and increased sustainability are some possible advantages that have been highlighted. Even though most fortune businesses have considered blockchain, the investment has significantly decreased. While blockchain technology has generated considerable interest and promise, the significant drop in investment among large firms can be attributed to several factors, including the technology's complexity and uncertainty, evolving regulatory challenges, the need for a clear return on investment, and competing priorities within organizations. As technology matures and demonstrates its usefulness in specific use cases, we may see an expansion of giant corporations' investment in blockchain, yet more measured and strategic.

Keywords: sustainable supply chain ; blockchain technology ; ISM

1. Blockchain Technology

The emergence of BT in 2009, through the development of Bitcoin by Nakamoto, was initially focused on financial integration ^[1]. However, the game-changing aspects of blockchain have encouraged sectors other than the financial industry to adopt it ^[2]. Many uses of BT have been identified in the literature, including healthcare management ^[3], the energy sector ^{[4][5]}, and digital government ^[6]. Additionally, SC network management has been identified as an enabler for BT, with most of the research focusing on four main themes: trust ^[7], trade ^[8], IoT ^[9], and traceability ^[10]. In spite of the potential advantages of SC integration with blockchain, barriers to adoption remain a significant challenge, including technological challenges, inadequate standards and trustworthiness, and interoperability ^[11]. An important research gap exists concerning the comprehensive assessment of barriers hindering the implementation of BT for SCM ^[12]. While some previous studies have investigated the adoption of BT, only a limited number have specifically addressed the barriers and challenges associated with its implementation, with the majority concentrating on adoption theories ^{[13][14]}.

2. Blockchain Integration in the Management of SSC

BT has gained recognition as a disruptive invention that can improve SSC ^[15]. The transparency and dependability of sustainable product creation can be increased by carefully monitoring the flows of goods along the SC and integrating BT. This can boost consumer trust by enhancing the credibility of the goods. Furthermore, blockchain can monitor social and environmental factors that could endanger sustainability, promoting both social and environmental sustainability ^[16]. There are two commonly used types of BT: public/permissionless and closed/permissioned ^[6]. Public blockchain networks enable anybody to join, access, and use blockchain ledgers. Public blockchains include Bitcoin and other cryptocurrencies. In contrast, private blockchains restrict access only to authorized users, while a hybrid model incorporating both public and private blockchains can be tailored to meet specific business needs. In the area of SCM, numerous use cases recommend adopting a private blockchain setup that allows only approved users with regulated access to exchange data ^[10]. Apart from SC applications, BT can also transform sustainability management in other areas. For instance, BT can be used to promote sustainability in the energy market by facilitating the sharing of energy in a sustainable manner ^[17]. The interrelationship of blockchain with the IoT can also help in managing SC issues ^[18]. BT might also aid in reducing information asymmetries that might limit small businesses and farms' access to chances for social and financial development. Additionally, blockchain can contribute to the sustainability of the socioeconomic system by minimizing illegal, fraudulent, and counterfeiting practices ^[19].

3. Barriers to Adopting Blockchain for SSC

3.1. IoT Related Barriers

BT has potential for SCM, but its adoption faces various barriers. Technical limitations like scalability, usability, and interoperability issues hinder implementation [20]. Latency problems result in slower transaction times and fewer transactions [21]. Security concerns, including vulnerability to hacking and system attacks, and conflicts between blockchain organizations can lead to “blockchain splitting” [22]. Limited access to blockchain information and data availability poses another challenge [23]. While data immutability is a key feature, it can be problematic if past errors persist indefinitely. The negative association with illegal activities on the “dark web” may hinder adoption, but increased familiarity and adoption may change public perception over time. The relationships between cryptocurrencies, blockchain technology, and unlawful activity on the “dark web” described are probably because these technologies have been employed in certain illegal transactions due to their pseudonymous nature. Criminals have used blockchain's immutability to hide their operations. Though the technology is neutral, it is important to understand that its implementations can have beneficial or bad effects [24].

3.2. Strategic Barriers

The adoption of BT in SCM is influenced by various internal factors and issues within organizations [25]. The implementation of BT requires substantial investments in hardware, software, maintenance, and infrastructure, particularly for larger implementations, posing financial challenges [26]. Additionally, cross-disciplinary involvement is necessary to ensure the integration of BT with environmental management, public relations, and corporate responsibility for sustainability. However, a lack of commitment from middle or upper management can negatively affect the perceived value of blockchain applications in SCM. Furthermore, if sustainability is not seen as a core value by management, the importance of blockchain technology may be overlooked. The lack of understanding and knowledge among enterprises regarding blockchain and sustainability hinders adoption [27]. Moreover, the absence of standardization in BT adds complexity to its adoption in SCM, making organizational adjustments for new blockchain and sustainability standards even more challenging. However, there is a chance that the potential advantages of blockchain technology in achieving sustainability goals may be disregarded or underestimated when sustainability is not seen as a fundamental value by management. Blockchain technology adoption as a tool for sustainability within a company is significantly influenced by management's priorities, vision, resource allocation choices, and influence on organizational culture [28][29].

3.3. Supply Chain Barriers

The adoption of BT in SCM is hindered by external barriers that are independent of businesses and technology. Inadequate communication and coordination among partners result in a lack of consumer understanding of the intersection between blockchain and sustainability, posing a significant challenge in SC issues [30]. Businesses often lack sustainability expertise and fail to implement sustainable practices throughout the SC, which complicates the integration of BT [31]. However, businesses are willing to share information if it benefits their consumers and ensures the security and privacy of their proprietary information, which BT can provide through encrypted blockchain and data security measures [32]. The sensitivity of sustainability information due to ethical and legal issues further amplifies these barriers. Reengineering business operations is necessary to overcome the challenges of integrating SC with sustainability and blockchain, but resource constraints may delay improvements in sustainable performance. Cultural and geographic diversity among SC partners can also make BT implementation challenging, as different notions of sustainability, particularly social sustainability, create difficulties in implementing consistent blockchain solutions [33].

3.4. Legislation Barriers

A legal barrier in blockchain technology is a problem or issue that prevents blockchain systems' use, adoption, or functioning because laws, regulations, or lack thereof cause it. These obstacles, which affect different parts of blockchain technology, may result from the legal and regulatory frameworks in a certain jurisdiction [34][35][36][37]. Government rules are still not totally in favor of BT, which makes it more difficult for it to be adopted in the SC. One major problem is the absence of governmental sustainability laws and frameworks, which hinder the development of integrated systems and blockchain standards [38].

3.5. External Barriers

The implementation of sustainability and blockchain in SCM is hampered by external parties from a wide range of sectors, including governments, businesses, institutes, communities, and non-governmental organizations [39]. These barriers may obstruct the integration of sustainability and blockchain, which would eventually impede efforts to grow the economy

sustainably and profitably. Another barrier is a lack of market knowledge and unpredictability, which can make companies fear the entry of new sustainable products into the market. This, in turn, makes BT even more necessary for an SSC [13].

However, based on the research and expert opinions, the authors identified the set of barriers indicated in **Table 1**.

Table 1. Barriers of implementing BT in SSC.

Primary Factor	Subfactor	Description	References
IoT barriers (B1)	Security challenge	Data security concerns include hacking, inaccurate information dissemination, and sensitive data access.	[40][41]
	Access to technology	Effective blockchain adoption depends on good internet and IT infrastructure access.	[42]
	Technological backlash	Negative perceptions about BT due to its association with cryptocurrencies hinder adoption.	[43]
	Consensus mechanisms	Immutability means records cannot be deleted, but incorrect records can be corrected with their history on the blockchain.	[38]
	Immaturity of technology	The scalability challenge is a technical issue arising from blockchain immaturity.	[27][44]
Strategic barriers (B2)	Financial constraints	High costs limit organization's ability to collect SC information and adopt sustainability practices.	[32][41]
	Unsupportive and uncommitted management	Managers' lack of commitment to sustainability and disruptive technology hinders SCM.	[45][46]
	Absence of BT policies	Defining new policies is necessary for organizations to adopt BT.	[21]
	Complications in changing organizational practices	Blockchain adoption transforms organizational culture with new work guidelines.	[21]
	Absence of resources for BT adaptation	Organizations face challenges in implementing blockchain and measuring sustainability due to a lack of standards.	[47]
SC barriers (B3)	Lack of customers awareness	Customers' lack of understanding of blockchain for SC sustainability practices.	[31]
	Lack of 3Cs	Performance is hampered by a lack of cooperation, coordination, and communication among SC partners.	[48]
	Difficulty in information sharing between SC parties	Data confidentiality, privacy, and financial value may present difficulties for the implementation of blockchain and SSC.	[41]
	Difficulties of integrating BT and sustainability through SCM	Integrating sustainability practices and blockchain into SCs requires technology, materials, and process development.	[49]
	Cultural differences of SC partners	Geographical or cultural differences among SC partners may hinder blockchain adoption.	[50]
Legislation barrier (B4)	Lack of legal framework	Businesses and organizations intending to implement blockchain technology may face confusion and regulatory issues in the absence of a legal framework.	[51]
	Lack of regulatory standards	Governments may be hesitant to promote blockchain and sustainability by creating regulatory standards.	[32][52]
	Smart contracts and legal validity	Traditional legal systems may fail to comprehend or adapt the distinct nature of smart contracts, resulting in confusion and significant legal stumbling blocks.	[41][53]
	Jurisdictional issues	Different countries' rules and regulations may contradict, complicating cross-border transactions and data management.	[36][37]
	Intellectual property rights	Determining ownership and protecting intellectual property assets inside a blockchain ecosystem might be difficult.	[34][35]

Primary Factor	Subfactor	Description	References
External barriers (B5)	Market rivalry and uncertainty	Sustainability and blockchain adoption may impact market competitiveness and involve uncertainty.	[41]
	Absence of involvement by external stakeholders	NGOs and communities may not fully support sustainable practices and BT.	[45]
	Lack of rewards and incentives	The industry lacks leadership in ethical and safe sustainability practices with blockchain.	[45]
	Lack of industry involvement in the adoption of blockchain	Lack of incentivization for sustainable blockchain practices by governments/professional organizations.	[41]

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