# Blockchain Technology for Viable Circular Digital Supply Chains: An Integrated Approach for Evaluating the Implementation Barriers

**Purpose -** Blockchain technology (BT) is creating a new standard for all business operations. It can assist businesses in handling the complexity of circular digital supply chain management. Despite this optimistic view, several barriers hinder its implementation. In this regard, this study contributes to Industry 4.0, Circular Economy, the viability with a critical emphasis on its potential ramifications and influence on the future agenda while using BT technology in supply chain (SC). In addition, the research reduces the knowledge gap by investigating and ranking the key barriers to the deployment of BT in viable circular digital supply chains (VCDSCs) and studies their interdependencies and causal relationships.

**Design/methodology/approach** – The barriers to BT adoption in VCDSC are identified through a thorough literature review and considering viability performance. These barriers are then classified using the AHP method. DEMATEL is then employed to examine the cause/effect, correlation, and connection among the 14 barriers selected barriers from the AHP classification to estimate each barrier's overall degree of impact over the others.

**Findings** – This paper identifies and analyses the BT adoption barriers in VCDSC as well as examines how the key barriers interact. As a result, according to the AHP/DEMATEL method, the most prominent influencing barriers to the BT implementation in VCDSC are "Data transparency", "Market competition", "Missing infrastructure", "Lack of standardization", "Complex protocol", "Lack of industry involvement", "Financial constraints", "Missing infrastructure", "Data transparency" and "Interoperability". The outcomes offer a potential path for identifying important barriers as well as insight into the implementation of BT in SC while integrating different capabilities such as viability, sustainability, and circular economy principles.

**Practical implications –** Managers and researchers will benefit from this research by gaining an understanding of the challenges that must be prioritized and examined for BT to be implemented successfully in VCDSC.

**Originality** - The use and implementation of Blockchain-enabled VCDSC continue to face challenges despite an increase in relevant practice and research. Despite the benefits of blockchain technology, managers struggle to apply such technology in the context of their company. In this respect, this paper uses an integrated AHP-DEMATEL for categorizing the BT barriers as well as the interrelationship between them. In this respect, this paper presents a

The BT barriers studied are those related to the use of BT in SC while integrating different paradigms such as viability, digitalization, and circular economy. While many studies look at the barriers to BT adoption, none of them has ever included the viable capability, which means the ability to "react agilely to positive changes, be resilient to absorb negative events and re-cover after disruptions and survive at long-term periods". The study concludes with insightful comments based on the findings and suggestions for eradicating those obstacles and their associated effects.
***Keywords:*** Blockchain technology, Circular supply chain Viability, Digital supply chain, Resilience, Agility, Sustainability, Resilience, Integrated AHP-DEMATEL.

## 1. Introduction

Digitalization, globalization, and natural disasters have all impacted most industrial sectors in recent years (Zekhnini et al., 2020). Consumers, governments, and managers throughout the world are pressuring businesses to manage their operations responsibly to enhance their sustainable performance. In this regard, Industry 4.0 (I4.0) technologies and Circular economy (CE) have been recognized as powerful parts of the sustainability and resilience response, assisting firms in becoming more viable Zekhnini et al., 2020). Circular digital supply chain management is defined as "the coordinated forward and reverse supply chains via purposeful business ecosystem integration for value creation from products/services, by-products, and useful waste flows through prolonged life cycles that improve the economic social and environmental sustainability of the organization while integrating different enabling technologies" (Chaouni Benabdellah *et al.*, 2021; Cherrafi *et al.*, 2022).

In light of the fourth industrial revolution, numerous technologies have disrupted the management of operations, which is an activity related to "*managing assets committed to the creation and supply of products and services*" (Babich and Hilary, 2020; Bag et al., 2021). To address all these issues, the adoption of Blockchain Technology (BT) is transforming businesses, as Industry 4.0 is aligned with CE's goals (Sanka *et al.*, 2021). In fact, "blockchain technology has the potential to solve significant glitches in traceability and surveillance along the chain. It enhances efficiency across all operations of the flow of goods, information about the storage and shipping of raw materials, delivering finished products from one point to another, and more. The results are a greater collaboration, streamlined inventory management, better asset usage, and more"(Srivastava and Dashora, 2022; Taqui *et al.*, 2022; Xiong *et al.*, 2021; Zekhnini, Cherrafi, Bouhaddou, Chaouni Benabdellah and Raut, 2021). Besides, traceability in SC is widely seen as being facilitated by BT, a distributed and unchangeable ledger for transaction records and tracking assets. Managers advocate a variety of initiatives such as "closed-loop supply chain design", "reverse logistics design", "industrial symbiosis collaboration", and "green marketing strategy" during the shift from a traditional supply chain to a CSC.

BT, a decentralized and distributed database that is used to keep track of an ever-growing collection of records, enables Digital Supply Chains (DSCs) to improve their sustainability, resilience, and agility (Sanka *et al.*, 2021). Furthermore, BT makes use of a data access infrastructure that refreshes itself in real-time and can execute financial transactions using computer algorithms without third-party validation (Bag *et al.*, 2023; Öztürk and Yildizbaşi, 2020a). Through the safe transmission of data in a distributed way, BT has the potential to enhance operations in various functions of an organization, including its SC (Lim *et al.*, 2021). Thus, the implementation of BT can increase customers' trust and, as a result, the performance improvement of the SC. By boosting effectiveness and transparency, BT has the potential to alter entire SCs. It enables businesses to improve their viability performance. More clearly, the viability is focused on long-term longevity without set time windows. It is the ability of SCs to sustain themselves and meet environmental necessities (sustainability) (Ivanov and Dolgui, 2020c). Especially, viability allows SCs to fulfil the demands of survivability in an evolving environment. Despite its benefits, many businesses are still hesitant to adopt BT (Kouhizadeh *et al.*, 2021a) as there are barriers to its adoption, particularly in terms of digitization, circularity, and viability.

Nevertheless, scientific research on the barriers to BT adoption has been limited. Some of the previous research has concentrated on the categorization of Technological, Organizational and External barriers for SC (Kouhizadeh et al., 2021a). Additional studies have focused on developing and analysing a systemic model of the barriers (Lohmer *et al.*, 2020). Furthermore, other researchers have investigated the barriers to BT adoption in traditional SCs (Öztürk and Yildizbaşi, 2020b; Sahebi *et al.*, 2020), sustainable SCs (Biswas *et al.*, 2013; Kouhizadeh *et al.*, 2021b) and circular SCs (Lim *et al.*, 2021; Nandi *et al.*, 2021). Others have studied the barriers to the implementation of BT in cold supply chains using the SEM method (Chavalala *et al.*, 2022) while others have developed an integrated model for understanding and predicting the determinants of BT and its effect on the performance of SMEs (Bag *et al.*, 2022). Therefore, the scientific debate on this topic is still going on, and more research is required before more generalised and robust conclusions can be drawn on the implementation of BT and its effectiveness to enhance sustainable and/or circular supply chains (Berdik *et al.*, 2021; Ghazi *et al.*, 2022; Kamble *et al.*, 2019). Moreover, a major problem in the adoption of new technology is the inconsistent communication among managers and engineers. On the CDSCM side, their intricate structure creates more barriers and conflicting challenges that prevent the adoption of BT while integrating different dynamic capabilities such as resilience, agility, digitalization, circularity, and sustainability. To the best of our knowledge, there has been limited research on the analysis and categorization of BT barriers for CSC using Multicriteria Decision Making methods. The general barriers framework for CSC provided by BT has not considered the viability and has not been stated.

In this context, no study has used integrated MCDM methods to examine BT barriers for CSC with the viability (robustness, agility, and resilience) concerns. This research addresses this gap by evaluating and analysing the barriers to BT adoption in viable circular digital supply chains (VCDSCs). We notice that the VCDSC refers to the capacity of a circular supply chain (SC) to preserve itself and thrive in a dynamic world by redesigning structures and replanning outcomes with long-term consequences while considering Industry 4.0 technologies.

Therefore, the barriers to BT adoption in VCDSC are identified through a thorough literature review while considering viability performance that includes the concepts of robustness, resilience, and agility. This step results in an analysis of 22 barriers categorized into five independent groups: (1) inter-organizational barriers; (2) intra-organizational barriers; (3) I4.0 technology barriers; (4) external barriers; and (5) social and environmental barriers. These barriers are then classified using the AHP method. DEMATEL is then employed to examine the cause/effect connection among the 14 barriers selected barriers from the AHP classification to estimate each barrier's overall degree of impact over the others. Following the (Alvesson and Sandberg, 2011; Sandberg and Alvesson, 2011) research questions guidelines, the following paper addresses the following research questions (RQ):

- RQ1: What are the key BT barriers in VCDSCs?
- RQ2: What are the causal relationships between these barriers?
- RQ3: Which barriers are the most prominent, influential, or resulting?

This article is structured as follows: In Section 2, the research background needed to prepare the foundations for the literature review is presented. Section 3 includes a state-of-the-art analysis of the current and past research dealing with BT and Sustainability, BT and resilience, BT and CE and BT and Industry 4.0 and introduces the identified BT barriers. Section 4 presents the research approach that was used to conduct the study. Section 5 presents the analysis and results of the classification of the identified barriers in VCDSCs using the AHP method and also presents the application of DEMATEL for the identified BT deployment barriers in VDSCs. Finally, Section 6 discusses and analyzes the findings as well as the implications for managers and practitioners while the conclusion and perspectives are drawn in the final section.

## 2. Research Background

In this section, key terms are defined and briefly discussed to lay the groundwork for the subsequent literature review.

### *2.1 Blockchain technology*

Blockchain technology gained notoriety as a robust decentralized data management and transaction platform after its launch in 2008 as the Bitcoin cryptocurrency (Nandi *et al.*, 2021). Since then, in addition to its cryptocurrency exhibition, it has been successfully used in a range of business applications, such as value-chain and supply chain (Narayan and Tidström, 2020; Qahtan *et al.*, 2022; Srivastava and Dashora, 2022). In fact, Blockchain is referred to as a "distributed ledger technology" that is based on an IT network that keeps track of digital asset exchanges. It makes use of distributed rather than traditional centralized databases (Min, 2019a), which are linked together via cryptographic technologies and a consensus process (Bali *et al.*, 2022; Lim *et al.*, 2021). More clearly, A blockchain is a collection of interconnected blocks, each of which contains a timestamp, a cryptographic hash of the block before it, and several transactions (Nofer *et al.*, 2017; Srivastava and Dashora, 2022). Once a payment update is generated in the platform, a block is created with a connection to the prior blocks and added to the distributed ledger based on this special data structure (Kouhizadeh *et al.*, 2021b). Instead, using central authorities and intermediaries, decentralized consensus based on the verification of the majority of parties is employed to confirm the legitimacy of transactions before they are added (Öztürk and Yildizbaşi, 2020b). In addition, nodes in the Blockchain system categorize operations into blocks (Sunmola and Apeji, 2020; Vivaldini and de Sousa, 2021a). It is the responsibility of the nodes to assess the legitimacy of transactions and whether they should be kept on the Blockchain. Furthermore, a single participant in a ledger cannot edit or remove block transactions (Bali *et al.*, 2022; Sunmola and Apeji, 2020). As a result, BT's fundamental is its potential to register share and verify transactions in encrypted and immutable ledgers in a public and open manner (Wang *et al.*, 2019). In a timed network system, BT provides a digitally transparent and open public ledger for all partners. Besides, the development and application of Blockchain technology are based on technological readiness, which is based on three factors according to (Hastig and Sodhi, 2020) framework:

- Technology maturity includes application examples of rising technology applications, technical flexibility, and infrastructure completion (Wang *et al.*, 2019).
- Data security includes application examples of data governance, platform credibility, user privacy, data credibility, and system vulnerabilities (Esposito *et al.*, 2018).
- Technical viability depends on factors including operating cost analysis, hardware facility energy usage, and hardware scalability (Chod *et al.*, 2020).

As a result, Blockchain technology is a ground-breaking new protocol that connects databases or ledgers in a decentralized, peer-to-peer, open-access network to share and update information. Blockchain technology is intended to guarantee that data is updated and stored in a safe, impenetrable, and irreversible manner. Besides, BT fosters confidence because of its open and cryptographic nature. Furthermore, it enables the creation of distributed cryptocurrencies such as Bitcoin, the implementation of digital contracts by themselves ("smart contracts"), and smart properties that can be administered over the internet.

*2.2 Viable supply chain*

The capacity of a supply chain (SC) to preserve itself and thrive in a dynamic world by redesigning structures and replanning outcomes with long-term consequences is known as viability. More clearly, the viability concept is based on robustness, resilience, and agility (Ivanov, 2020; Zekhnini, Cherrafi, Bouhaddou, Chaouni Benabdellah and Bag, 2021). Stability is the ability to restore the system to its pre-disturbance and maintain its continuity while robustness is the ability to continue an intended performance in the face of disruption (Simchi-Levi *et al.*, 2018). In contrast, resilience is "*defined as the capability to recover from disruptions*" (Hosseini *et al.*, 2019; Lotfi *et al.*, 2021). Thus, a viable supply chain (VSC) is a dynamically adaptable and structurally changeable value-adding network able to (i) react agilely to positive changes, (ii) be resilient to absorb negative events and recover after the disruptions, and (iii) survive at the times of long-term, global disruptions by adjusting capacity utilization and their allocations to demands in response to internal and external changes in line with sustainable developments to secure the provision of society and markets with goods and services with a long-term perspective (Ivanov, 2020; Zekhnini, Cherrafi, Bouhaddou and Benabdellah, 2021). Therefore, a viable system focuses primarily on managing management, processes, and the environment, and viability in particular enables systems to meet the requirements of "survivability" in a developing environment. Because there are no predetermined time constraints, the viability analysis is concentrated on "long-term longevity" (Zekhnini, Cherrafi, Bouhaddou, Chaouni Benabdellah and Bag, 2021).

### *2.3 Circular supply chains*

The linear economic model has governed our civilization since the industrial revolution, but it is nowadays becoming unsustainable. Organizations now recognize that our world has limited resources and that we are approaching such resource limits. Our ecosystems are still being contaminated by the disposal of wastes created by a linear economy-based industrial system. As an alternative model, CE has emerged in multi-level supply chain networks to confront the difficult task of tracking material reuse through many life cycles (Huang *et al.*, 2022). Besides, the numerous risks and uncertainties that the global economy faces, as well as the pressing need to promote creativity and innovative ways of value creation, serve as the foundation for the need to implement CE (Govindan, 2022). With the capacity to address those needs, CE holds out the promise of a strong methodology. So, a question arises: What is CE? The CE is "*characterized as an economic model in which resources are used for as long as possible while extracting maximum value. By reducing (or delaying) unintended negative environmental impacts, the principles of CE broaden the boundary of green, resilience, and sustainable SCM*" (Bag *et al.*, 2020; Sassanelli *et al.*, 2020). As the globe comes closer to a CE, SCs players are becoming more conscious of their environmental impact. SCs in a CE are considered as "open-loop supply chains," "circular supply chains," and "closed-loop supply chains" (Geissdoerfer *et al.*, 2017; Nandi *et al.*, 2021). As a result, CSCM contains a vision of a waste-free economy as well as regenerative and restorative cycles that are organized utilizing circular thinking(Okorie *et al.*, 2018). In other words, CSCMs vary from the classic SCMs in two major aspects. First, traditional SCM relies on using resources efficiently, whereas CSCM focuses on how to utilize them in an environmentally friendly manner. Second, traditional SCM uses only rejected products to create another one that is less valuable than the original while CSCM focuses on repurposing wasted resources and products to create others with higher value (Garrido-Hidalgo *et al.*, 2020).

*2.4 Digital supply chain*

In recent decades, technological and computational developments have resulted in a fast-changing environment. To address the issues of volatility, resilience, unpredictability, and transparency, businesses require a digital supply chain (DSC) that is built on sustainability, visibility, efficiency, and flexibility (Büyüközkan and Göçer, 2018; Zekhnini, Cherrafi, Bouhaddou, Benghabrit, *et al.*, 2020). According to (Büyüközkan and Göçer, 2018), DSCs can be considered as "an intelligent best-fit technological system that is based on the capability of massive data disposal and excellent cooperation and communication for digital hardware, software, and networks to support and synchronize interaction between organizations by making services more valuable, accessible and affordable with consistent, agile and effective outcomes". This suggests that corporations must mix sophisticated technology with human resources to turn their SCs from being conventional to being integrated and intelligent (Rauniyar *et al.*, 2022). As a result, DSCs are concerned with how SCs are managed, and how both digital processes contribute to improved quality, real-time, and visibility at all levels (Liu and Li, 2020; Rane and Narvel, 2021). In other words, DSCs will have a full picture of all the information provided and shared among all the participants as well as a real-time response across all levels via the achievement of transparency, responsiveness, flexibility, communication, and collaboration along the supply chain (Zekhnini, Cherrafi, Bouhaddou and Benghabrit, 2021).

## 3. Literature Review

The usage of BT is crucial to assist the handling of SC activities due to technological improvements, notably in information management (Büyüközkan and Göçer, 2018; Di Vaio and Varriale, 2020; Gupta *et al.*, 2020). Nonetheless, the emergence of BT introduces a modern perspective on SCM (Liu and Li, 2020; Zekhnini, Cherrafi, Bouhaddou, Benghabrit, *et al.*, 2020). Due to a variety of causes like human error, interrupted systems, and environmental concerns, SCs are getting more unpredictable. As a result, traditional SCs have tried to meet the demands of customers. To do so, intelligent, interconnected, circular, agile, resilient, and sustainable SCs are the current operation management trend ( Zekhnini et al., 2021). This new tendency refers to having more viable CDSCs (Gupta *et al.*, 2020). The viability is considered in this paper as a critical SC asset that encompasses resilience, agility, and sustainability. In the subsequent subsections, we identify and analyze research papers dealing with BT for resilient DSC, BT for agile SC, BT for sustainable SC, and BT for circular SC.

### *3.1 BT for resilient digital supply chain*

BT, which is being developed as a new type of transformative internet technology, may be able to assist in addressing intermediary risks such as data breaches, political instability, hacking, financial volatility, contractual disputes, government regulations, and costly compliance (Min, 2019a; Sharma *et al.*, 2022; Zekhnini, Cherrafi, Bouhaddou, Chaouni Benabdellah and Raut, 2021). BT assists also participants in monitoring digital data while considering a variety of additional activities, such as digital signatures for preventing and responding to digital disturbances, such as fraud (Di Vaio and Varriale, 2020; Vivaldini and de Sousa, 2021a). During disruptions, BT may support resilience techniques to enhance agility, communication, visibility, and efficiency in DSC (Dubey *et al.*, 2020; Nandi *et al.*, 2021). As a result, by facilitating cost-effective and faster product delivery, improving product transparency, boosting stakeholder cooperation, and enabling access to resources, blockchain may significantly enhance resilience in SCs (Bayramova *et al.*, 2021). Furthermore, blockchain allows parties to communicate with one another (Vivaldini and de Sousa, 2021b). This results in a more efficient process with lead times, less redundancy, reduced waste, and shorter SCs (Zekhnini, Cherrafi, Bouhaddou and Benabdellah, 2021). It also guarantees that standards are met, allowing the supplier to have eater control over the product's development through the whole product lifecycle (Lohmer *et al.*, 2020). Besides, BT can provide numerous managerial advantages to everyday business operations, including “Reduced transaction costs/time” because of better-maintained blockchain platforms which do not require the participation of third parties (Rane and Narvel, 2021). It also increases visibility throughout the supply chain because of more transparent open ledgers that anybody can access (Taqui *et al.*, 2022; Vivaldini and de Sousa, 2021a). In addition to that, BT enhanced connectivity between trading partners due to the fusion of the digital and physical worlds, including shared awareness of information and transaction throughout the supply chain (Qahtan *et al.*, 2022; Taqui *et al.*, 2022; Techlab, 2017)

### *3.2 BT for agile supply chain*

Agility is defined “*as the capacity to recognize and exploit competitive possibilities quickly. It is about introducing improvement in a method that is suitable, adaptable, and responsive to* *changes in the marketplace*" (Cao *et al.*, 2019; Zhu *et al.*, 2022). As a result, more agile SCs are required, notably in the case of the COVID-19 pandemic (Nandi *et al.*, 2021; Zhu *et al.*, 2022). To so do, the adoption of BT can assist supply chain agility in this situation. In fact, according to (Nandi *et al.*, 2021), BT improves supply chain visibility, traceability, responsiveness, performance, and authenticity. Additionally, it helps E2E actors share, communicate, collaborate, and compromise while also enhancing productivity (Nandi *et al.*, 2021). Furthermore, employing transparent BT in inventory and manufacturing management gives accurate and transparent data, allowing production technologies to be more agile (Zekhnini, Cherrafi, Bouhaddou, Benghabrit, *et al.*, 2020). As a result, it enhances SC agility, particularly when combined with various I4.0 technologies (Vivaldini and de Sousa, 2021b). Thus, organizations can rapidly adapt to environmental adjustments from third parties because of the agility built by BT. Because of its flexibility, companies may better plan to restructure assets, plans, and operations in partnership with other supply chain members. Therefore, given the benefits of blockchain, such as transparency, efficiency, and others (Abeyratne and Monfared, 2016; Debabrata and Albert, 2018; Staples *et al.*, 2017), blockchain technology can effectively assist businesses to increase supply chain visibility (Zhu *et al.*, 2022). Information or data can be stored and shared quickly and effectively within a supported distributed ledger system, such as a blockchain supported shared ledger system, such as blockchain, information or data can be stored and distributed quickly and effectively (De Angelis, 2022). Additionally, blockchain technology can decrease manual interaction, such as a mid-check (De Angelis, 2022; Stege, 2018; Taqui *et al.*, 2022).

### *3.3 BT for sustainable supply chain*

In the SCM literature, the importance of addressing sustainability is underlined (Esmaeili *et al.*, 2017; Govindan, 2022). DSCs should address sustainability to achieve long-term value stream competitiveness (Kouhizadeh *et al.*, 2021a). Besides, it has been difficult to solve sustainability challenges in developing countries due to low levels of trust and high financial intermediaries' costs (Kshetri, 2021). To achieve these issues, BT plays a critical role in the growth of a sustainable SC since it has the potential to revolutionize sustainability concerns (Kouhizadeh *et al.*, 2021b). In fact, prior studies have shown that this technology is essential for building trust, supporting the decentralization of markets, and supporting the decentralization of conventional governance and business models (Govindan, 2022; Gurtu and Johny, 2021; Kshetri, 2021). As a result, corporations are deploying BT to tackle several environmental supply chain challenges utilizing immutable and decentralized data, transparency, traceability, and smart contracts, in response to growing sustainability issues (Boutkhoum *et al.*, 2021; Kouhizadeh *et al.*, 2021b). In addition to that, Blockchain aids in the reduction of data volatility that might endanger the social and financial viability of SCs by decreasing illicit actions and through the dependability, transparency, and security of BT features (Kouhizadeh *et al.*, 2021b). BT keeps also a detailed record of supply chain activities that aid firms in increasing product authenticity and reducing rework and recall (Boutkhoum *et al.*, 2021; Esmaeili *et al.*, 2017). Furthermore, BT can detect environmental and social issues that may damage environmental concerns (Sunmola and Apeji, 2020). Therefore, considering all these benefits and advantages, BT technology is considered the most promising technology to gain sustainability concerns in SCs by shortening transaction times and lowering transaction fees.

*3.4 BT for circular supply chain*

The CE and BT are two emerging revolutionary concepts that have the potential to revolutionize companies, and the global economy on a technological, economic and social level (Huang *et al.*, 2022; Morales *et al.*, 2022; Okorie *et al.*, 2018). CE comprises a complete approach to conscientious material choice, to maintaining items at their optimum utility through manufacturing, operation, and reuse cycles via the application of closed loops

(Cherrafi *et al.*, 2022). More clearly, through a decentralized ledger where resources and goods can be traced back to their origin, a blockchain enables a secure, quick, and available digital platform (Chaouni Benabdellah *et al.*, 2021). Furthermore, as the CE strives for cleaner production plans (Esken *et al.*, 2018; Hens *et al.*, 2018), BT can enable cleaner production of services and products while also addressing the ethical ideology of corporate development (Govindan *et al.*, 2020). In this respect, to address these issues, a variety of methods and approaches have been tried and evaluated. Some researchers have demonstrated that BT supports traceability, information security, and sustainability in the whole SC (Francisco and Swanson, 2018; Saberi *et al.*, 2019). Others have proposed frameworks to assist in the adoption of BT by determining how the product lifecycle might be improved (Akram *et al.*, 2020; Leng *et al.*, 2020). Other researchers have used the same perspective but studied BT from different perspectives (Batwa and Norrman, 2020; Remko, 2020; Treiblmaier, 2018). Thus, natural resources may be tokenized on the blockchain, resulting in a unique digital signature that can be exchanged. This raises the value of resources enabling a new natural system of trading and pricing, as well as motivating persons to adopt CSC. As a result, BT has several potential benefits, including prospects for better supply chains through increased trust, better interoperability, enhanced security, greater auditability, etc (Erol *et al.*, 2022; Nandi *et al.*, 2021). Although the precise advantages of using BT can differ in supply chains, the main takeaway is that blockchain offers a foundation for solving many major circular supply chain adoption barriers (Kayikci *et al.*, 2022; Nandi *et al.*, 2021).

*3.5 BT barriers identification*

Based on the previously studied papers that have been located from different databases, we have collected an extensive list of barriers to the adoption of BT for VCDSC based on the following keywords: “BT barriers for Viable Supply Chain”, “BT barriers for Sustainable Supply Chain”, “BT barriers for Digital Supply chain”, “BT barriers for Intelligent Supply chain” and “BT barriers for Circular Supply chain”. Iterative development was used to create the keywords and terms used in searches. The authors began by using a brainstorming technique, and as keywords were discovered in the literature, they added them to the search using a snowballing process. Besides, the resulting search phrases were merged using the Boolean operators (AND/ OR). Therefore, depending on the content of the literature review, we list the factors to empirically evaluate the barriers to Blockchain implementation for VCDSC, as illustrated in figure 1.

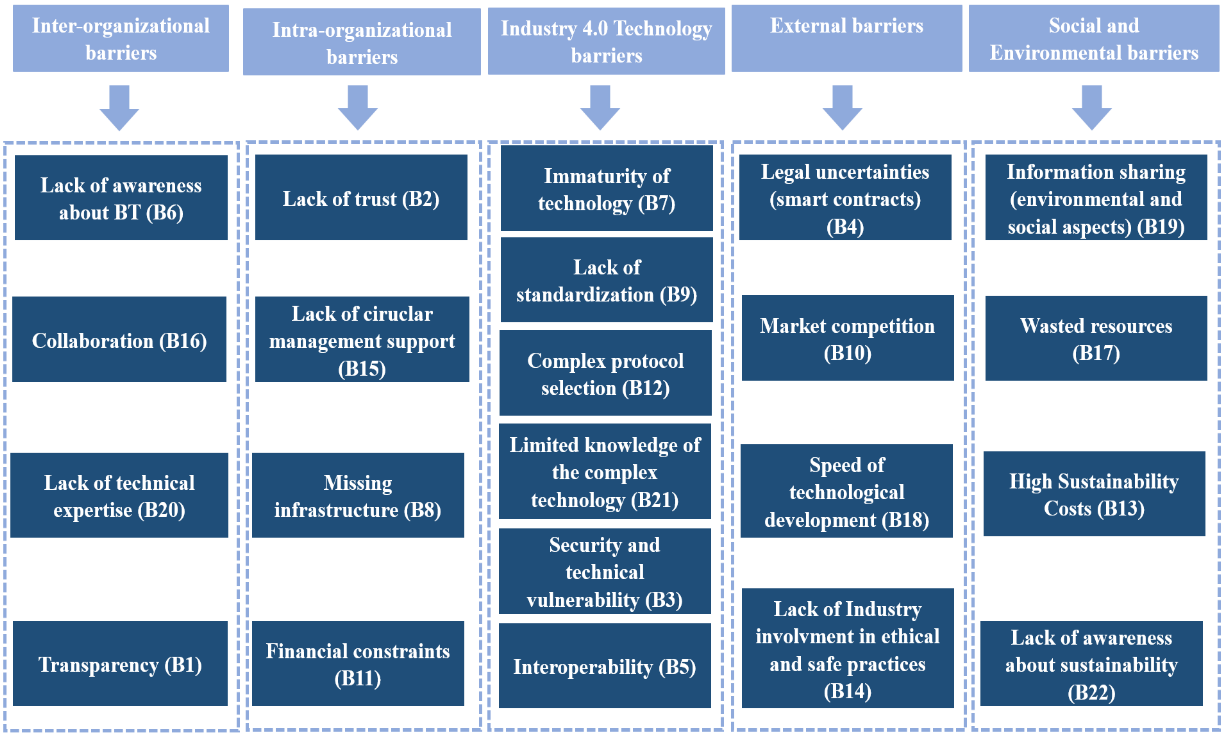


**Figure 1:** Barriers to implementing Blockchain technology in VCDSC

More clearly, the list of the BT barriers considered for VCDSC is divided into five main groups:

- Inter-organizational barriers include mainly all the BT barriers related to the circular supply chain transparency, collaboration as well as the lack of awareness of BT and the lack of technical expertise (Lim *et al.*, 2021; Min, 2019a; Yadav and Singh, 2020). It also includes several barriers such as a lack of customer awareness, problems in communication, collaboration and coordination in the CSC (Erol *et al.*, 2022; Farooque *et al.*, 2019). It also considers the cultural differences between the supply chain actors as well as all challenges related to integrating BT through SC as well as sustainable and resilient partners (Govindan, 2022; Mangla *et al.*, 2018).

- Intra-organizational includes all BT barriers related to the lack of circular management support as well as the financial constraints related to the implementation of BT in circular supply chains. It includes also barriers such as the lack of trust and the missing infrastructure needed to implement the benefits of BT barriers (Bacudio *et al.*, 2016a; Lim *et al.*, 2021; Min, 2019a). Besides, barriers such as lack of BT tools implementation, lack of customer tendency and awareness as well as lack of management support and commitment includes in this category;
- I4.0 technology barriers  include all BT barriers concerning the industry 4.0 technologies such as the immaturities of actors about the benefits of each technology, the lack of standardization, the security and technical vulnerability as well as the complex protocol standardization and the interoperability between all the infrastructures and systems (Bacudio *et al.*, 2016b; Lim *et al.*, 2021; Min, 2019a);
- External barriers include all the BT barriers related to external environment fluctuation such as the legal uncertainties related to smart contracts, the market competition, and the speed of technological development without missing the lack of industry involvement in ethical and safe practices (Bacudio *et al.*, 2016b; Lim *et al.*, 2021; Min, 2019b; Yadav and Singh, 2020). It includes also the lack of external stakeholder involvement, lack of encouragement programs as well as rewards;
- Social and environmental barriers include all the BT technologies related to the two pillars of sustainability such as wasted resources, lack of awareness about sustainability, the lack of information sharing as well as the high costs resulting from the implementation of sustainability practices (Kouhizadeh *et al.*, 2021a; Öztürk and Yildizbaşi, 2020a).

## 4. Research Methodology

Recent research studies have advanced our understanding of numerous SC difficulties and decision-making processes (Bag *et al.*, 2018, 2020; Benabdellah *et al.*, 2020; Cabral *et al.*, 2012; Chai and Ngai, 2020; Nandi *et al.*, 2021; Zekhnini, Cherrafi, Bouhaddou and Benghabrit, 2020). Moreover, several studies covering a wide range of subjects have been proposed to investigate the effects of adopting BT in SCs to make them more resilient, sustainable, and digital (Bag *et al.*, 2020; Kouhizadeh *et al.*, 2021b; Min, 2019a; Wang *et al.*, 2019). Thus, to "provide a historical perspective of the appropriate study topic and an in-depth assessment of independent research endeavours", we conducted first a literature analysis to look into and debate historical and current research on the barriers to the adoption of the BT in SCs to guarantee each of the sustainable, resilience, circular, and digital capabilities, as well as the integration of them. The general step-by-step research methodology followed in this study to evaluate and examine BT adoption in VCDSC is depicted in Figure 2.

The proposed methodology is divided into four stages. Throughout the literature study, the initial phase involved identifying BT adoption barriers. It entailed compiling a complete list of potential roadblocks to BT's implementation in VCDSCs.

The second phase hierarchised and prioritized the identified barriers using Analytical Hierarchy Process (AHP) classification approach. That is, after constructing the logical AHP structure, as summarized in (Saaty, 2004), the option of developing pair-wise comparisons that indicate the relationship between the criteria, objectives, alternatives, and sub-criteria in a hierarchical manner for each of the studied criteria can be carefully analyzed. After all of the comparisons were completed and the comparable weights for each of the criteria were examined and evaluated, the relative weights were determined. Finally, to measure the consistency of the data obtained, the consistency ratio (CR) was computed, which should be less than 0.10. Once the consistency was validated, the ranking prioritization of the evaluated criteria was obtained.

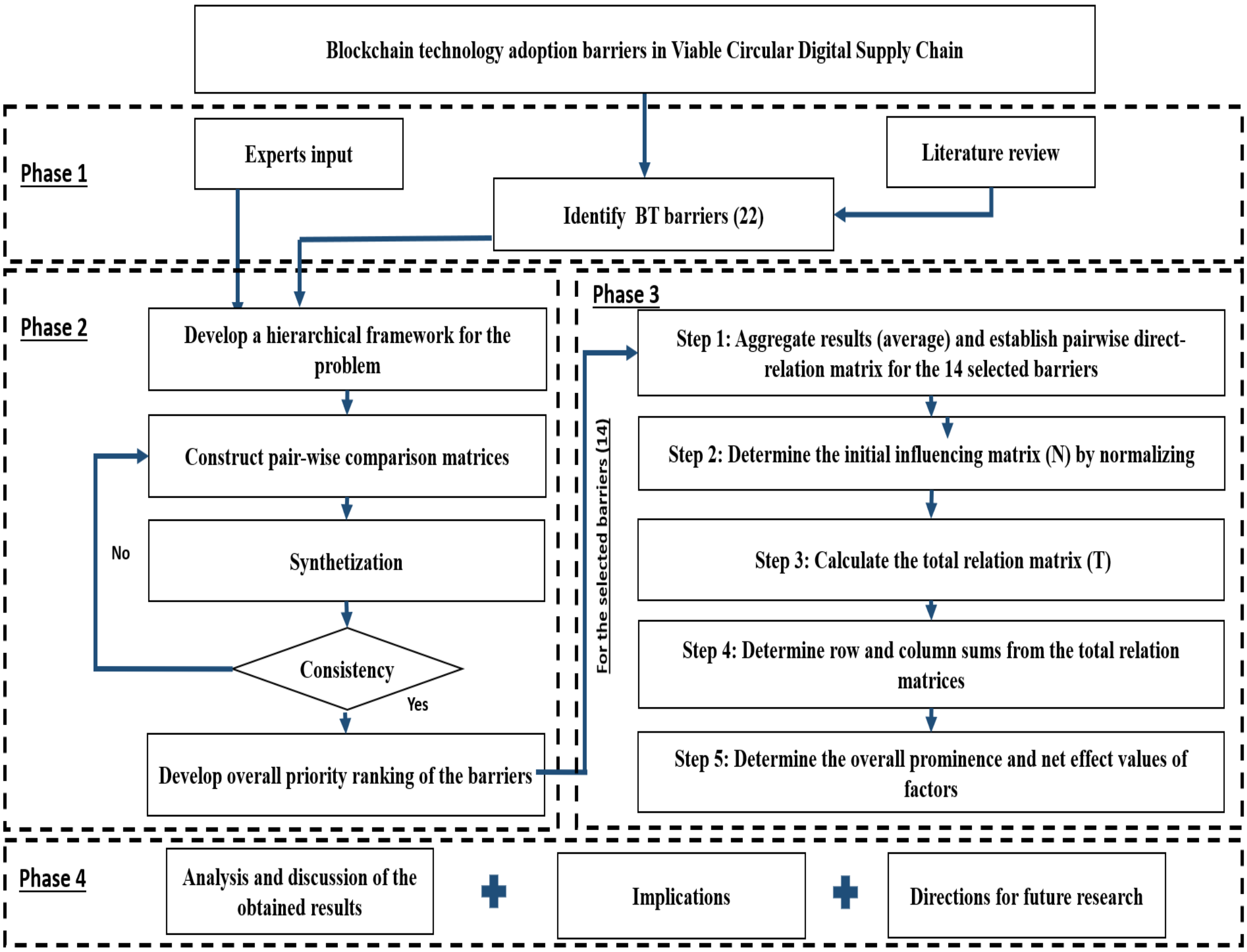


**Figure 2.** Research methodology

The third phase involved assessing the identified barriers. Using the DEMATEL method, the defined BT barriers were explored at this stage by following the following five steps: (1) Creating a “pairwise relation matrix” and aggregating the results; (2) Normalizing the “initial influence matrix” (N); (3) Calculating the “total relation matrix” (T); (4) Using the “total relation matrices” to calculate column and row sums and (5) Calculating the overall prominence and net effect values. Finally, the fourth step consisted of reviewing and debating the previous phases, as well as offering future research perspectives and some managerial and practical implications.

As a summary, the combined method (AHP-DEMATEL) seeks first to prioritize the BT barriers and then to include a digraph as well as a cause-and-effect diagram to show how one aspect affects the other. In fact, this combined method has the benefit of measuring and evaluating the subjective expert judgments in a quantifiable manner (Büyükozkan & Güleryüz, 2016; Tseng, 2011). Because a single approach is insufficient for a thorough and accurate investigation of the problem in this study, we combine the AHP and DEMATEL methodologies. As a result, DEMATEL-AHP has benefits over existing MCDM techniques since it shows the link between the variables and ranks them according to their relevance and the type of their interaction. In fact, decision-makers frequently use the AHP to efficiently include various elements in solving complicated situations. However, when capturing success elements directly by employing AHP, decision-makers could overlook the interdependencies among success variables. By grouping components into "cause-and-effect clusters", DEMATEL may assess the intricate interconnections between them (Gandhi, Mangla, Kumar, & Kumar, 2016), creating a hierarchical structure for practical solutions (Yang, Shieh, Leu, & Tzeng, 2008). However, the ISM method establishes also links between factors (variables) according to their interdependence and driving power, but it does not judge the magnitude of their impacts.

## 5. Integrated Approach for Evaluating the Implementation of BT Barriers in VCDSC: AHP- DEMATEL

The importance of adopting BT has grown in recent years. BT initiatives are being undertaken by businesses to attain high performance. Unfortunately, numerous barriers and problems stand in the way of its execution. Identification of the essential constraints that limited BT's deployment in VCDSC is critical for its effective deployment (Mills, 2001). In this section, we present the data collection as well as the classification method results (AHP + DEMATEL) to select the most prominent barriers and then analyse and identify cause and effect interactions between them.

*5.1 Data collection and selection of experts*

Data collection is the first step in determining the prioritization and cause/effect interrelation between the BT barriers. To ensure the performance of the model and the generality of its conclusions, it is necessary to have a panel of experts from various positions and with different backgrounds. As a result, 4 professionals from various industries and 3 academic specialists in the field consented to take part in the research through direct visits and email exchanges. The 7 members, who had over ten years of expertise, form a team that contributed in comprehensively investigating the identified BT barriers. In this line, the experts' team was composed of one IT manager, one supply chain manager, one operation general manager, one quality manager, and three professors specializing in BT and SCM. Table I summarises the expert's profile. Once the expert team was formed and during the first meeting, the 22 identified barriers have been studied (See section 4). Based on their responses using the AHP multi-criteria classification method, the 14 most significant roadblocks to BT's VCDSC implementation were determined. The experts' team was asked again to assess the impact of each barrier on the others during a second meeting. In the final meeting, the experts discussed and validated the findings.

**Table I:** Expert profile

| Position | Academic background | Years of experience |
| --- | --- | --- |
| IT Manager (1) | Not mentioned | 8- 10 years |
| Supply Chain Manager (1) | MBA degree | |
| Operation general Manager (1) | Engineering degree | |
| Quality manager (1) | Phd degree | |
| Professors in BT and SCM (3) | PhD degree with SCM certificates | |

*5.2 Barriers prioritization and classification: AHP*

To identify and rank the most relevant barriers that needed to be considered when implementing VCDSC, the AHP multi-criteria method was employed (Benabdellah *et al.*, 2020; Zekhnini, Cherrafi, Bouhaddou and Benghabrit, 2020). Analyzing with AHP begins with the definition of a decision hierarchy, followed by a set of criteria, and lastly a collection of selected alternatives. To do so, we established the barriers hierarchy as presented in Figure 3 and used pair-wise comparisons to determine the impact of BT adoption barriers on VCDSCs. This step necessitated the creation of an "AHP model hierarchy". It is worth noting that the first level of the hierarchy represents our purpose, which is to prioritize the VCDSC barriers. The factors utilized to make our decision were represented in the second level of the hierarchy. As a result, five primary categories of barriers were established to achieve our goal, namely: (1) intra-organizational barriers, (2) Industry 4.0 technology barriers, (3) inter-organizational barriers, (4) social & environmental barriers, and (5) external barriers. The third hierarchy level was made up of 22 obstacles divided into the five categories previously established. In VCDSCs, the fourth hierarchy level comprised the outcomes, which corresponded to the effective prioritization of the barriers.

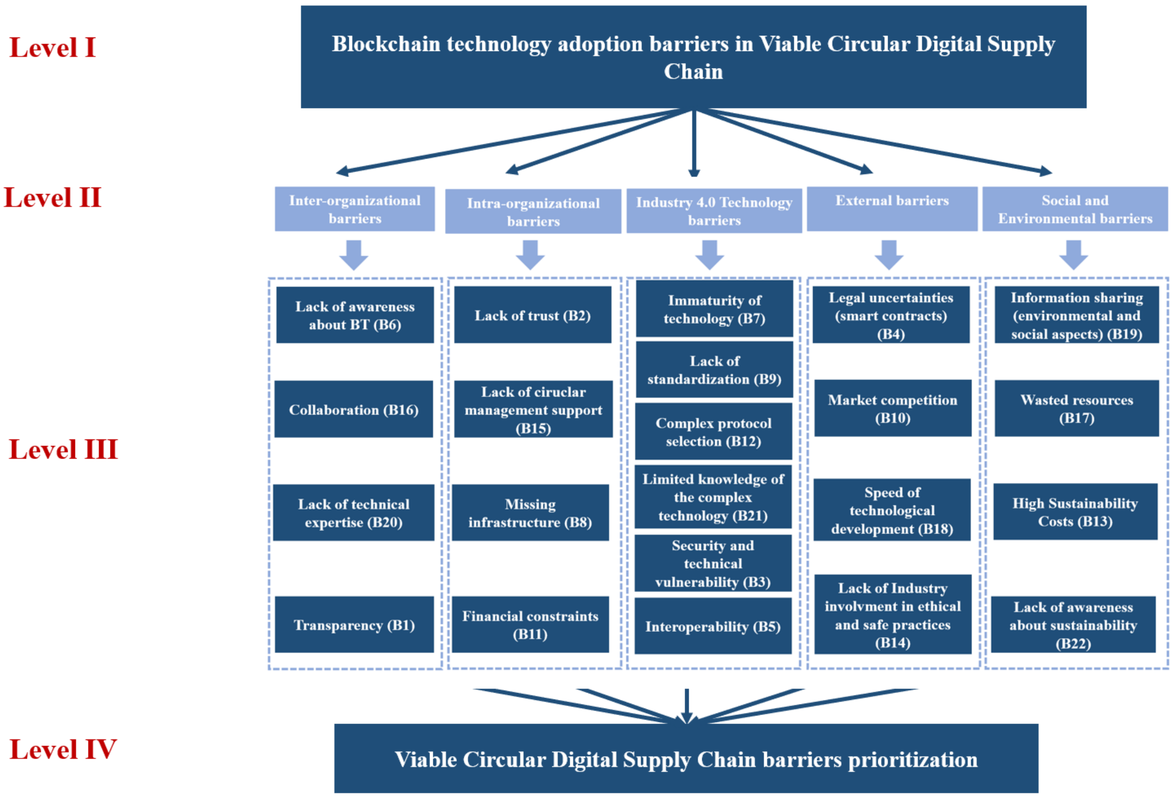


**Figure 1.** Hierarchy of barriers

The second stage in the AHP method consisted in developing and using the pair-wise comparison matrix to calculate the relative weights for the criterion. Given the evaluation matrix with pairwise comparisons, the geometric mean of each row was used to estimate the appropriate largest left eigenvector. That is, the components are multiplied in each row together and the "n-th root" is the number of elements calculated in the row. Following that, and in accordance with the AHP methodology, Table II and Table III present the "pairwise comparison matrix" for a different level of hierarchy as well as the barriers ranking. The "pairwise comparison decision matrices" were built with expert opinions to estimate the "relative importance" of the VCDSC barriers. However, one of the important AHP tasks is to measure the estimated consistency ratio (CR) which should be less than 0.10 or less according to (Saaty, 2004) In our context for both pair-wise matrices, the CR was 0.09 for the barriers category and 0.07 for sub-barriers respectively.

**Table II**. Pair-wise comparisons of barriers categories

| Barriers | Inter-organizational barriers | Industry 4.0 technology barriers | Intra-organizational barriers | External barriers | Social and environmental barriers | Weights |
|---|---|---|---|---|---|---|
| **Inter-organizational** | 1 | 3 | 7 | 5 | 5 | **0,449** |
| **Industry 4.0 technology** | 1/3 | 1 | 3 | 7 | 5 | **0,276** |
| **intra-organizational** | 1/7 | 1/3 | 1 | 2 | 2 | **0,116** |
| **External barriers** | 1/5 | 1/7 | ½ | 1 | 2 | **0,090** |
| **Social and environmental** | 1/5 | 1/5 | ½ | 1/2 | 1 | **0,068** |

As presented in Table II and according to the barriers ranking, the crucial barriers that need practitioners' attention can be determined. The most important barrier category referred to the *Inter-organizational barriers*, which are mainly related to the "lack of technical expertise", "awareness and collaboration", and "transparency" (Lim *et al.*, 2021; Min, 2019a; Yadav and Singh, 2020). The second most important barrier referred to *Industry 4.0 technology barriers,* i.e. "immaturity of the technology", "complex protocol selection" and "limited knowledge" of the complex technologies (Bacudio *et al.*, 2016b; Lim *et al.*, 2021; Min, 2019a).

**Table III**. Pair-wise comparisons of sub-barriers categories (22)

| Barriers | B12 | B3 | B22 | B13 | B21 | B17 | B4 | B9 | B16 | B14 | B5 | B6 | B10 | B15 | B8 | B1 | B19 | B11 | B2 | B7 | B18 | B20 | Weights |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B12** | 1,00 | 0,14 | 5,00 | 3,00 | 5,00 | 5,00 | 0,33 | 0,33 | 0,33 | 5,00 | 0,20 | 0,20 | 0,33 | 5,00 | 7,00 | 5,00 | 5,00 | 0,20 | 0,14 | 0,20 | 0,14 | 5,00 | 1,83 |
| **B3** | 7,00 | 1,00 | 9,00 | 7,00 | 9,00 | 3,00 | 0,33 | 0,33 | 3,00 | 7,00 | 0,33 | 0,33 | 5,00 | 5,00 | 9,00 | 7,00 | 5,00 | 0,33 | 0,33 | 3,00 | 9,00 | 7,00 | 3,37 |
| **B22** | 0,20 | 0,11 | 1,00 | 0,11 | 3,00 | 0,33 | 0,11 | 0,14 | 0,20 | 0,33 | 0,14 | 0,14 | 0,14 | 0,33 | 0,20 | 0,14 | 0,14 | 0,20 | 0,11 | 0,14 | 0,14 | 5,00 | 0,26 |
| **B13** | 0,33 | 0,14 | 9,00 | 1,00 | 5,00 | 7,00 | 0,20 | 0,20 | 3,00 | 0,33 | 3,00 | 3,00 | 0,20 | 0,14 | 3,00 | 0,20 | 0,33 | 0,14 | 0,20 | 3,00 | 5,00 | 3,00 | 1,44 |
| **B21** | 0,20 | 0,11 | 0,33 | 0,20 | 1,00 | 0,20 | 0,14 | 3,00 | 0,14 | 0,20 | 0,33 | 0,33 | 0,14 | 0,14 | 0,20 | 0,11 | 0,14 | 0,20 | 0,14 | 0,20 | 0,11 | 0,20 | 0,36 |
| **B17** | 0,33 | 0,33 | 3,00 | 0,14 | 5,00 | 1,00 | 0,33 | 5,00 | 5,00 | 0,33 | 0,20 | 0,20 | 0,20 | 0,20 | 0,33 | 0,20 | 0,33 | 3,00 | 0,20 | 0,33 | 3,00 | 0,33 | 0,95 |
| **B4** | 3,00 | 3,00 | 9,00 | 5,00 | 7,00 | 3,00 | 1,00 | 5,00 | 3,00 | 5,00 | 0,33 | 0,33 | 3,00 | 0,33 | 5,00 | 0,33 | 7,00 | 5,00 | 3,00 | 3,00 | 7,00 | 7,00 | 2,94 |
| **B9** | 3,00 | 3,00 | 7,00 | 5,00 | 0,33 | 0,20 | 0,20 | 1,00 | 5,00 | 3,00 | 0,20 | 0,20 | 3,00 | 3,00 | 7,00 | 0,20 | 7,00 | 3,00 | 0,33 | 5,00 | 5,00 | 7,00 | 2,43 |
| **B16** | 3,00 | 0,33 | 5,00 | 0,33 | 7,00 | 0,20 | 0,33 | 0,20 | 1,00 | 0,33 | 0,33 | 5,00 | 0,33 | 5,00 | 0,20 | 0,20 | 3,00 | 0,33 | 0,20 | 0,33 | 3,00 | 5,00 | 1,11 |
| **B14** | 0,20 | 0,14 | 3,00 | 3,00 | 5,00 | 3,00 | 0,20 | 0,33 | 3,00 | 1,00 | 3,00 | 3,00 | 0,33 | 0,33 | 0,33 | 0,33 | 3,00 | 0,20 | 0,14 | 0,20 | 5,00 | 5,00 | 1,14 |
| **B5** | 5,00 | 3,00 | 7,00 | 0,33 | 3,00 | 5,00 | 3,00 | 5,00 | 3,00 | 0,33 | 1,00 | 0,20 | 3,00 | 5,00 | 0,14 | 0,20 | 5,00 | 7,00 | 0,33 | 3,00 | 7,00 | 7,00 | 2,59 |
| **B6** | 5,00 | 3,00 | 7,00 | 0,33 | 3,00 | 5,00 | 3,00 | 5,00 | 0,20 | 0,33 | 5,00 | 1,00 | 0,20 | 7,00 | 0,20 | 0,20 | 7,00 | 5,00 | 0,33 | 0,20 | 7,00 | 7,00 | 2,51 |
| **B10** | 3,00 | 0,20 | 7,00 | 5,00 | 7,00 | 5,00 | 0,33 | 0,33 | 3,00 | 3,00 | 0,33 | 5,00 | 1,00 | 5,00 | 0,20 | 0,33 | 7,00 | 0,33 | 3,00 | 0,33 | 5,00 | 7,00 | 1,96 |
| **B15** | 0,20 | 0,20 | 3,00 | 7,00 | 7,00 | 5,00 | 3,00 | 0,33 | 0,20 | 3,00 | 0,20 | 0,14 | 0,20 | 1,00 | 0,14 | 0,14 | 3,00 | 0,20 | 0,20 | 0,20 | 0,33 | 0,20 | 1,02 |
| **B8** | 0,14 | 0,11 | 5,00 | 0,33 | 5,00 | 3,00 | 0,20 | 0,14 | 5,00 | 3,00 | 7,00 | 5,00 | 5,00 | 7,00 | 1,00 | 0,20 | 7,00 | 5,00 | 0,33 | 0,20 | 7,00 | 5,00 | 2,40 |
| **B1** | 0,20 | 0,14 | 7,00 | 5,00 | 9,00 | 5,00 | 3,00 | 5,00 | 5,00 | 3,00 | 5,00 | 5,00 | 3,00 | 7,00 | 5,00 | 1,00 | 9,00 | 0,33 | 3,00 | 0,14 | 7,00 | 5,00 | 3,26 |
| **B19** | 0,20 | 0,20 | 7,00 | 3,00 | 7,00 | 3,00 | 0,14 | 0,14 | 0,33 | 0,33 | 0,20 | 0,14 | 0,14 | 0,33 | 0,14 | 0,11 | 1,00 | 0,33 | 0,20 | 0,14 | 5,00 | 0,20 | 0,58 |
| **B11** | 5,00 | 3,00 | 5,00 | 7,00 | 5,00 | 0,33 | 0,20 | 0,33 | 3,00 | 5,00 | 0,14 | 0,20 | 3,00 | 5,00 | 0,20 | 3,00 | 3,00 | 1,00 | 0,33 | 0,33 | 7,00 | 3,00 | 1,99 |
| **B2** | 7,00 | 3,00 | 9,00 | 5,00 | 7,00 | 5,00 | 0,33 | 3,00 | 5,00 | 7,00 | 3,00 | 3,00 | 0,33 | 5,00 | 3,00 | 0,33 | 5,00 | 3,00 | 1,00 | 7,00 | 5,00 | 9,00 | 3,27 |
| **B7** | 5,00 | 0,33 | 7,00 | 0,33 | 5,00 | 3,00 | 0,33 | 0,20 | 3,00 | 5,00 | 0,33 | 5,00 | 3,00 | 5,00 | 5,00 | 7,00 | 7,00 | 3,00 | 0,14 | 1,00 | 3,00 | 5,00 | 2,70 |
| **B18** | 7,00 | 0,11 | 7,00 | 0,20 | 9,00 | 0,33 | 0,14 | 0,20 | 0,33 | 0,20 | 0,14 | 0,14 | 0,20 | 3,00 | 0,14 | 0,14 | 0,20 | 0,14 | 0,20 | 0,33 | 1,00 | 5,00 | 0,76 |
| **B20** | 0,20 | 0,14 | 0,20 | 0,33 | 5,00 | 3,00 | 0,14 | 0,14 | 0,20 | 0,20 | 0,14 | 0,14 | 0,14 | 5,00 | 0,20 | 0,20 | 5,00 | 0,33 | 0,11 | 0,20 | 0,20 | 1,00 | 0,52 |

The third most important barriers category was considered those referring to *Intra-organizational barriers*, i.e. ‘lack of infrastructure’, ‘standardization’, ‘trust and management support’ (Bacudio *et al.*, 2016a; Lim *et al.*, 2021; Min, 2019a). The fourth important barriers category was found to be that of *External barriers*, which are related to “market competition”, “speed of technological development” and “legal uncertainties” (Bacudio *et al.*, 2016b; Lim *et al.*, 2021; Min, 2019b; Yadav and Singh, 2020). The last important barriers category was determined to be *Social and environmental barriers* that are related to “waste resources”, “lack of tendency about sustainability” and “awareness” as well as “information sharing” (Kouhizadeh *et al.*, 2021a; Öztürk and Yildizbaşi, 2020a). In terms of sub-barriers ranking, as presented in Table III, it can be concluded that in order to implement VCDSC, the top 14 barriers are: Data transparency (B2), Lack of trust (B3), Security and technical vulnerability (B7), Legal uncertainties (B8), Interoperability (B10), Lack of awareness (B1), Immaturity of technology (B5), Missing infrastructure (B9), Lack of standardization (B6), Market competition (B14), Financial constraints (B4), Complex protocol (B13), High Sustainability costs (B12), Lack of industry involvement (B11). Therefore, the 22 identified barriers initially determined could be reduced to 14 based on the analysis conducted.

However, as previously discussed, and according to the literature analysis, there are few pieces of research on BT adoption barriers for VCDSC. Furthermore, as far as the authors are aware, no research has considered the BT adoption barriers while integrating the digitization, sustainability, and resilience paradigms using an integrated AHP-DEMATEL approach. Therefore, given the increased number of disruptions that SCs may encounter, it is critical to understand obstacles from a cause-and-effect perspective.

*5.3 Analysis of the cause-effect relationship amongst BT barriers in VCDSC: DEMATEL*

The first stage is to conduct a "pair-wise comparison matrix" using the DEMATEL scales. In this context, '0' indicates that there was no influence between the factors while '1' indicates that there was a very low influence between them. The '2' and '3' indicate respectively that there was a low influence and medium influence. The '4' indicates that there was a high influence between the factors, whereas '5' suggested a very high influence. Thus, the impact of barrier *i*" on "*j*" is represented by the matrix $A_K = [a_{ijk}]_n$, where "*n*" is the number of barriers and "$k$" is the number of experts. Furthermore, because barriers cannot impact themselves, their diagonal has a value of '0'.

$$A_k = \begin{bmatrix} 0 & a_{12k} & a_{13k} & & \cdots & a_{12k} & a_{1nk} \\ a_{21k} & 0 & a_{23k} & & \cdots & 0 & a_{2nk} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{(n-1)1k} & a_{(n-1)2k} & a_{(n-1)3k} & & \cdots & 0 & a_{(n-1)nk} \\ a_{n1k} & a_{n2k} & a_{n3k} & & \cdots & a_{n(n-1)k} & 0 \end{bmatrix} \quad (1)$$

As a consequence, the "total direct connection matrix $A_k$" is then calculated using the formula A=$\frac{[a_{ij}]}{k}$, where $a_{ij}$ is the average of all experts' $a_{ijk}$. Thus, Table IV presents "the pairwise direct relation matrix" in VCDSCs.

**Table IV.** The "pairwise direct relation matrix" in VCDSC

| Barriers | Index | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 | B12 | B13 | B14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lack of awareness | B1 | 0 | 1 | 3 | 1 | 0.4 | 1.6 | 1.3 | 2.1 | 0.9 | 3.6 | 2.9 | 2.57 | 0.4 | 2.7 |
| Data transparency | B2 | 2.14 | 0 | 4 | 0.4 | 0.9 | 3.6 | 3.9 | 1 | 0.3 | 0.6 | 2.9 | 0.29 | 2.7 | 3.1 |
| Lack of trust | B3 | 2.14 | 0 | 0 | 0.9 | 0.7 | 1.7 | 0.9 | 3.7 | 0 | 2.9 | 0.3 | 0.57 | 1.3 | 2 |
| Financial constraints | B4 | 0.29 | 0 | 0 | 0 | 2.9 | 2.9 | 0.4 | 2.9 | 0.4 | 1.6 | 0.1 | 3.57 | 2.4 | 3.6 |
| Immaturity of technology | B5 | 2,86 | 3 | 2 | 2 | 0 | 2,9 | 2,9 | 2,9 | 3,7 | 2,9 | 2,9 | 0,14 | 2,9 | 2,7 |
| Lack of standardization | B6 | 1,43 | 3 | 4 | 1,3 | 2,9 | 0 | 2,9 | 1,3 | 1,1 | 1,6 | 1,6 | 1,71 | 2,1 | 1,3 |
| Security and technical vulnerability | B7 | 0,29 | 4 | 4 | 1 | 2,9 | 2,9 | 0 | 2,1 | 2,6 | 2,9 | 3,6 | 0,29 | 1,4 | 2,7 |
| Legal uncertainties | B8 | 0,14 | 1 | 3 | 1,9 | 0,4 | 2,3 | 1 | 0 | 1 | 3 | 0,1 | 1,86 | 0,3 | 0,3 |
| Missing infrastructure | B9 | 0,43 | 3 | 3 | 2,9 | 3,6 | 3,6 | 2,9 | 0,4 | 0 | 2,7 | 2 | 2 | 1,3 | 3 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Interoperability** | **B10** | 3,14 | 4 | 4 | 1,1 | 1,1 | 2,9 | 1 | 0,1 | 1,9 | 0 | 1,4 | 3,29 | 1,9 | 1,3 |
| **Lack of industry involvement** | **B11** | 0.14 | 4 | 3 | 2.6 | 1.3 | 2.9 | 2.9 | 0.3 | 3 | 2.4 | 0 | 2.43 | 0.4 | 0.9 |
| **High Sustainability costs** | **B12** | 0.29 | 0 | 0 | 3 | 1 | 0.7 | 0.1 | 0.1 | 3.1 | 0.7 | 2.4 | 0 | 0.4 | 3 |
| **Complex protocol** | **B13** | 0.86 | 3 | 3 | 2 | 0.3 | 1.3 | 2.9 | 0.1 | 0.1 | 3.1 | 0.7 | 0.43 | 0 | 2 |
| **Market competition** | **B14** | 0.14 | 0 | 1 | 2.9 | 0.3 | 2.9 | 0.1 | 1.1 | 1.7 | 2.9 | 3.1 | 4 | 1.7 | 0 |

Once the connection matrix was obtained, the matrix A was then normalized (Table V) in the second phase given a normalized "total direct relation matrix" N by using the following formula:

$$N= [b_{ij}]_{n*n}=\frac{A}{\max\limits_{1\leq i\leq n}\sum_{j=1}^{n} a_{ij}} \text{ where } 0\leq b_{ij} \leq 1. \quad (2)$$

**Table V.** Pairwise direct relation matrix

| | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **B8** | **B9** | **B10** | **B11** | **B12** | **B13** | **B14** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | 0.00 | 0.03 | 0.09 | 0.03 | 0.01 | 0.05 | 0.04 | 0.06 | 0.03 | 0.11 | 0.09 | 0.08 | 0.01 | 0.08 |
| **B2** | 0.06 | 0.00 | 0.12 | 0.01 | 0.03 | 0.11 | 0.12 | 0.03 | 0.01 | 0.02 | 0.09 | 0.01 | 0.08 | 0.09 |
| **B3** | 0.06 | 0.00 | 0.00 | 0.03 | 0.02 | 0.05 | 0.03 | 0.11 | 0.00 | 0.09 | 0.01 | 0.02 | 0.04 | 0.06 |
| **B4** | 0.01 | 0.00 | 0.00 | 0.00 | 0.09 | 0.09 | 0.01 | 0.09 | 0.01 | 0.05 | 0.00 | 0.11 | 0.07 | 0.11 |
| **B5** | 0.08 | 0.09 | 0.06 | 0.06 | 0.00 | 0.09 | 0.09 | 0.09 | 0.11 | 0.09 | 0.09 | 0.00 | 0.09 | 0.08 |
| **B6** | 0.04 | 0.09 | 0.12 | 0.04 | 0.09 | 0.00 | 0.09 | 0.04 | 0.03 | 0.05 | 0.05 | 0.05 | 0.06 | 0.04 |
| **B7** | 0.01 | 0.12 | 0.12 | 0.03 | 0.09 | 0.09 | 0.00 | 0.06 | 0.08 | 0.09 | 0.11 | 0.01 | 0.04 | 0.08 |
| **B8** | 0.00 | 0.03 | 0.09 | 0.06 | 0.01 | 0.07 | 0.03 | 0.00 | 0.03 | 0.09 | 0.00 | 0.06 | 0.01 | 0.01 |
| **B9** | 0.01 | 0.09 | 0.09 | 0.09 | 0.11 | 0.11 | 0.09 | 0.01 | 0.00 | 0.08 | 0.06 | 0.06 | 0.04 | 0.09 |
| **B10** | 0.09 | 0.12 | 0.12 | 0.03 | 0.03 | 0.09 | 0.03 | 0.00 | 0.06 | 0.00 | 0.04 | 0.10 | 0.06 | 0.04 |
| **B11** | 0.00 | 0.12 | 0.09 | 0.08 | 0.04 | 0.09 | 0.09 | 0.01 | 0.09 | 0.07 | 0.00 | 0.07 | 0.01 | 0.03 |
| **B12** | 0.01 | 0.00 | 0.00 | 0.09 | 0.03 | 0.02 | 0.00 | 0.00 | 0.09 | 0.02 | 0.07 | 0.00 | 0.01 | 0.09 |
| **B13** | 0.03 | 0.09 | 0.09 | 0.06 | 0.01 | 0.04 | 0.09 | 0.00 | 0.00 | 0.09 | 0.02 | 0.01 | 0.00 | 0.06 |
| **B14** | 0.00 | 0.00 | 0.03 | 0.09 | 0.01 | 0.09 | 0.00 | 0.03 | 0.05 | 0.09 | 0.09 | 0.12 | 0.05 | 0.00 |

The "total relation matrix" (T) was calculated in the third phase using (equation

3), where I refers to the “identity matrix” (Table VI).

$$T = [t_{ij}]_{n*n} = M[I - T]^{-1} \qquad (3)$$

**Table VI.** Total relation matrix

| | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 | B12 | B13 | B14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | 0.08 | 0.15 | 0.25 | 0.14 | 0.1 | 0.2 | 0.14 | 0.15 | 0.12 | 0.12 | 0.24 | 0.19 | 0.11 | 0.21 |
| **B2** | 0.14 | 0.15 | 0.3 | 0.13 | 0.13 | 0.27 | 0.24 | 0.14 | 0.12 | 0.19 | 0.21 | 0.13 | 0.18 | 0.24 |
| **B3** | 0.12 | 0.09 | 0.12 | 0.1 | 0.08 | 0.16 | 0.1 | 0.17 | 0.07 | 0.19 | 0.09 | 0.11 | 0.1 | 0.15 |
| **B4** | 0.07 | 0.11 | 0.14 | 0.11 | 0.16 | 0.22 | 0.11 | 0.16 | 0.1 | 0.17 | 0.11 | 0.21 | 0.16 | 0.22 |
| **B5** | 0.19 | 0.28 | 0.31 | 0.22 | 0.14 | 0.32 | 0.25 | 0.22 | 0.24 | 0.3 | 0.25 | 0.18 | 0.23 | 0.28 |
| **B6** | 0.13 | 0.23 | 0.3 | 0.16 | 0.19 | 0.18 | 0.21 | 0.15 | 0.14 | 0.22 | 0.18 | 0.17 | 0.17 | 0.2 |
| **B7** | 0.12 | 0.29 | 0.34 | 0.18 | 0.21 | 0.3 | 0.16 | 0.19 | 0.2 | 0.28 | 0.26 | 0.16 | 0.18 | 0.26 |
| **B8** | 0.06 | 0.11 | 0.2 | 0.13 | 0.08 | 0.17 | 0.1 | 0.07 | 0.09 | 0.18 | 0.08 | 0.13 | 0.08 | 0.11 |
| **B9** | 0.12 | 0.26 | 0.31 | 0.23 | 0.23 | 0.32 | 0.24 | 0.14 | 0.14 | 0.27 | 0.22 | 0.21 | 0.18 | 0.27 |
| **B10** | 0.18 | 0.25 | 0.3 | 0.16 | 0.14 | 0.26 | 0.16 | 0.11 | 0.16 | 0.17 | 0.18 | 0.22 | 0.17 | 0.2 |
| **B11** | 0.1 | 0.26 | 0.28 | 0.2 | 0.16 | 0.27 | 0.22 | 0.12 | 0.2 | 0.23 | 0.14 | 0.2 | 0.13 | 0.19 |
| **B12** | 0.05 | 0.09 | 0.1 | 0.17 | 0.1 | 0.13 | 0.08 | 0.06 | 0.16 | 0.12 | 0.15 | 0.09 | 0.08 | 0.18 |
| **B13** | 0.1 | 0.19 | 0.23 | 0.15 | 0.09 | 0.18 | 0.18 | 0.09 | 0.08 | 0.21 | 0.12 | 0.11 | 0.09 | 0.18 |
| **B14** | 0.07 | 0.12 | 0.17 | 0.19 | 0.1 | 0.22 | 0.1 | 0.11 | 0.14 | 0.21 | 0.19 | 0.23 | 0.14 | 0.13 |

Based on the prior study, the complete relation matrix's row (C) and column (R) sums were determined in the fourth phase (T). That is, the overall influence of barrier *i* on barrier *j* is represented by *R*. Barrier *i* total influence from barrier *j* is denoted by the letter *C*. To explain the interaction of the BT barriers, a causal diagram was built by putting “RC values” and then building a “directed graph” after finding the overall prominence and net effect values. If the (RC) value of a barrier was larger than zero, it belonged to the cause group. If a barrier's (RC) value was less than zero, it belonged to the effect group. Thus, the net impact and overall prominence values are presented in Table VII.

**Table VII.** Net impact and overall prominence values

| Barriers | Index | R | C | R+C | Rank | R-C | Cause/Effect |
|---|---|---|---|---|---|---|---|
| **Lack of standardization** | **B8** | 1.59 | 1.88 | 3.47 | 14 | -0.29 | **Effect** |
| **Interoperability** | **B1** | 2.2 | 1.53 | 3.73 | 13 | 0.67 | **Cause** |
| **Security and technical vulnerability** | **B12** | 1.56 | 2.34 | 3.9 | 12 | -0.78 | **Effect** |
| **Immaturity of technology** | **B13** | 2 | 2 | 4 | 11 | 0 | **Neutre** |
| **Data transparency** | **B4** | 2.05 | 2.27 | 4.32 | 10 | -0.22 | **Effect** |
| **Lack of industry involvement** | **B14** | 2.12 | 2.82 | 4.94 | 9 | -0.7 | **Effect** |
| **Missing infrastructure** | **B3** | 1.65 | 3.35 | 5 | 8 | -1.7 | **Effect** |
| **Lack of trust** | **B9** | 3.14 | 1.96 | 5.1 | 7 | 1.18 | **Cause** |
| **Market competition** | **B11** | 2.7 | 2.42 | 5.12 | 6 | 0.28 | **Cause** |
| **Financial constraints** | **B2** | 2.57 | 2.58 | 5.15 | 5 | -0.01 | **Effect** |
| **Complex protocol** | **B5** | 3.41 | 1.91 | 5.32 | 4 | 1.5 | **Cause** |
| **High Sustainability costs** | **B7** | 3.13 | 2.29 | 5.42 | 3 | 0.84 | **Cause** |
| **Lack of awareness** | **B10** | 2.66 | 2.86 | 5.52 | 2 | -0.2 | **Effect** |
| **Legal uncertainties** | **B6** | 2.63 | 3.2 | 5.83 | 1 | -0.57 | **Effect** |

In Figure 4, the couple “(R-C; R+C)” was used to generate the “cause-and-effect diagram”. The horizontal axis (R+C) quantifies a barrier's prominence, demonstrating its entire impact in terms of affected and influential power. (R-C) is the vertical axis that illustrates the barriers' causal-effect connection.

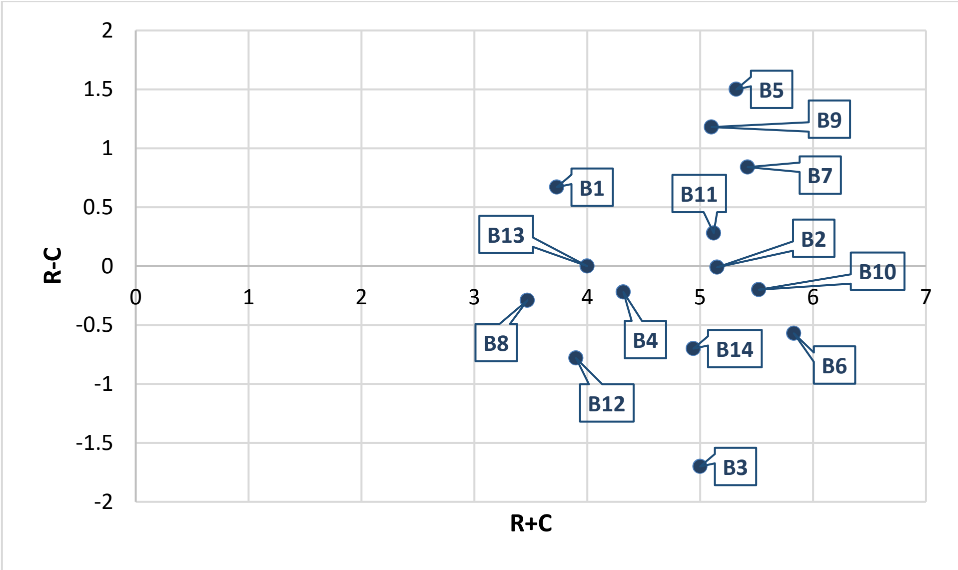


**Figure 4.** Cause and effect diagram

## 6. Discussion and Implications

### *6.1 Discussion*

DEMATEL is one of the most important instruments that must be presented adequately in order to be correctly comprehended. Based on the previous analysis, we evaluate three barrier categories (influential, prominent, and resulting) to examine the relationships between them for BT adoption in VCDSCs. Thus, the most influencing barriers that have an important impact on the BT implementation in VCDSC are "Lack of industry involvement", "Financial constraints", "Missing infrastructure", "Data transparency ", "Interoperability" and "Complex protocol". In this respect, adopting BT may be a particular challenge in CDSCs if data transparency and interoperability are lacking or incorrectly established and the industry has an immaturity of infrastructures and technologies. These impediments are tied to advancements in technology as well as security concerns.

The prominence score of prominent barriers was high, indicating that they have a strong relationship with other barriers and have a significant impact on others. To support the effective deployment of BT inside their VCDSCs, stakeholders must understand and overcome these barriers (Bai *et al.*, 2020). According to the results, the most prominent barriers to the effective implementation of the BT in VCDSC are “Data transparency”, “Market competition”, “Missing infrastructure”, “Lack of standardization” and “Complex protocol”. “Lack of standardization”, according to (Babich and Hilary, 2020), is a serious barrier since it causes technological uncertainty. Our findings are consistent with the most recent “global blockchain survey from Deloitte” (Insights, 2019), which listed the prominent barriers to implementing blockchain technology for supply chains as “joining consortia or networks”. Managers are advised by the findings that to expand and improve their usage of blockchain, they must find partners for their supply chains. It is vital to persuade, reward, and create innovative ways to encourage partners - both downstream and upstream - to join the whole CSC. These adoption initiatives might be supported by legal arrangements, preferential selection, and measures that encourage learning and partner and learning development.

Furthermore, (Min, 2019b) contends that Blockchain standards should be created to define how operations are organized, secured, and certified in networks. Furthermore, as the most prominent barrier is “Data Transparency”, organizational systems are required to enable decentralizing networks and allow E2E transparency in order to provide a standards-based application (Min, 2019b). As a result, organizations should regularly evaluate business plans, address the key reasons for barriers, and spend on assets that will aid in the implementation of BT in VCDSCs. To effectively realize BT's prospects, stakeholders should rely on clear initiatives. Besides, the results suggest that governments can become involved in blockchain implementation earlier by promoting investments in and developments around blockchain through flexible and regulations policies. Therefore, to ensure the safety of every user, firms can evaluate the markets for innovative solutions with the help of the government inside of legal frameworks (Kayikci *et al.*, 2022).

The “resulting barriers” are the ones that are most affected. As a result, companies must consider them after examining other ones. In this study, the “resulting barriers” refer to “Interoperability”, “Financial constraints”, “Immaturity of technology”, “Lack of trust”, “Lack of industry involvement”, “Legal uncertainties”, “High Sustainability costs”, and “Security and technical vulnerability”. Other barriers have a significant influence on the variables that arise. For example, industries continue to view “data transparency” as a big danger. In other words, it might be a stumbling block when transmitting critical information in real-time (Wang *et al.*, 2019).

In this regard, the five different barrier categories for blockchain adoption in VCDSC that were examined in this study are preliminary and exploratory, but they do give managers of supply chains and policy-makers actionable information to start discussing challenges and organizing strategies to overcome barriers related to the adoption of BT. Besides, issues with coordination, information sharing and collaboration, among supply chain participants, as well as difficulties integrating VCDSC and BT, are of the greatest priority. More clearly, Blockchain implementation requires finding the proper partners to create efficient governance frameworks (Erol *et al.*, 2022; Yadav and Singh, 2020). There will need to be clear disclosure standards that allow for the safeguarding of some sensitive and confidential information. As a result, by fostering organizational cultures that support a collaborative ecosystem for technological advancement, these barriers can be removed.

To summarize, Figure 5 presents the causal interrelationships of BT barriers to VCDSCs.

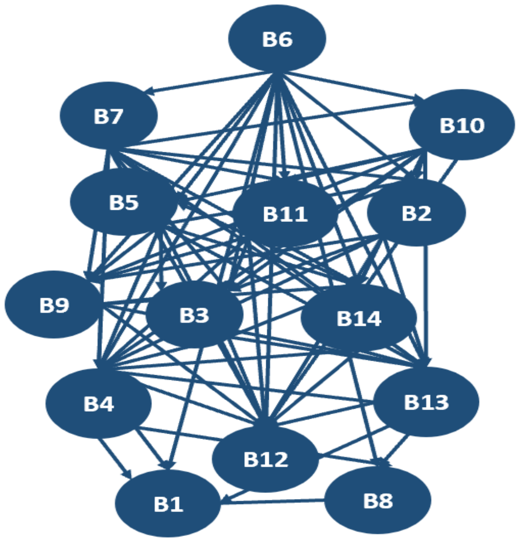


**Figure 5.** Causal interrelationships of BT barriers in VCDSC

Companies must implement strategies to consider a variety of causes, and the resulting aspects should only be examined once the key “influencing barriers” have been identified. Therefore, it's critical to start by removing the major barriers before moving on to the next.

Therefore, since most SC are not geographically isolated but rather linked to the world through trade, the increased use of BT has the potential to be a catalyst for implementation as well as a disruptive force. This can assist SC-stakeholders in gaining trust and collaborating in using blockchain and reduce uncertainty about this emerging technology (Viano *et al.*, 2022). Besides, to fully utilize BT and be capable to provide their customers with the best solutions, technology companies need to arm themselves with cutting-edge skills. Similarly, combining BT with enabling technologies like cloud computing, IoT, BDA and data visualization gives enormous possibilities for developing new technical solutions. In the same way, BT is still developing and needs time, blockchain technical developers are required to develop a solution to all privacy and security concerns to boost customer happiness. As a result, this study demonstrates that the adoption of BT improves the viability of the CSC based on its financial component as a contributor to supply chains' economic resilience and sustainability.

Along with prioritizing the BT adoption barriers in VCDSC as well as the evaluation of their causal interaction, this study presents evidence of managerial and theoretical implications of implementing BT in VCDSC which is covered in more detail in the next sections.

*6.2 Implications for theory*

The present research and its results have ramifications for both practitioners and academics. They addressed barriers that need to be overcome and it serves as a guide for managers, as this study focuses on the most important barriers to BT implementation in VCDSCs. It will also assist researchers in raising their awareness and prioritizing the barriers that must be overcome. To achieve the effective deployment of BT in VCDSCs, enterprises must create effective procedures and strategies. Besides, to solve BT's adoption difficulties, managers must concentrate on enhancing the technical obstacles, according to our results. Therefore, it's critical to remember that technology limitations exist regardless of the organizational structure.

Furthermore, in this technical environment, transparency, openness, security, transparency, dependability, and neutrality for all SC participants are possible (Bali *et al.*, 2022; Rane and Narvel, 2021). Additionally, when an organization improves its capacity for achieving these objectives, it could also become much more adaptive and responsive to external changes that affect its SC. The overall results support the idea that technological maturity, Data transparency, and lack of standardization are crucial factors. BT enables organizations to develop new offerings in a shorter amount of time and reconfigures DSC in response to changes in stakeholder demand.

In contrast to earlier research, the strategy of CSC as well as viable integration in the use of Blockchain technology adoption is clarified in this study. This is done by bolstering the management of circular principles as well as viable digital control mechanisms. Overall, our study adds to the theoretical framework for Blockchain supported by circular economy and viability for DSC while offering some new insights. This is important for theoretical development and practical advice since most of the study concentrated just on embracing blockchain technology (see for example (Orji *et al.*, 2020)) instead of attempting to comprehend the barriers and difficulties.

*6.3 Implications for practice*

This study contributes to managers in several ways. Our findings aid a company's CDSC managers' (or CEOs') efforts to develop a deeper comprehension of their plans to integrate BT into the supply chain. According to (Boutkhoum *et al.*, 2021), blockchain technology is not yet developed enough, and there is a shortage of technological infrastructure. In this respect, Managers should focus on building roadmaps and long-term strategies to take advantage of BT to boost technical capacity. Managers should analyze prospective use cases and discover blockchain functions that are compatible with other technologies.

Besides, the management of enterprises must explain regulations on the use of BT in SC activities. Furthermore, establishing new roles and duties, as well as establishing knowledge, will be necessary to support Blockchain-enabled (Mendling et al., 2018) on which both the retailer and manufacturer are affected. Moreover, Blockchain is a very complicated technology from the viewpoint of those involved in the supply chain, and many individuals are unaware of all its complexities and implications (Hunhevicz & Hall, 2020). Additionally, because it introduces numerous new concepts like cryptography, private, and public, it is difficult for the entire value chain to implement the technology. Another serious barrier to the implementation of BT and CDSC is a “lack of trained human resources” in the field (Oztürk & Yildizbasi, 2020). As a result, we advise managers to stress the importance of knowledge training in SCM.

The recommended methodology and results obtained can be used by researchers in different manufacturing and industrial fields. The findings remind CEOs that to expand and enhance the success of blockchain implementation, they must engage people in their SCs to put BT's capabilities to be used. Moreover, the results also suggest that technological maturity could indirectly promote circular concerns and information disclosure, enriching managers' tools to improve the performance of circular management throughout the SC.

Furthermore, our research indicates that it is crucial for managers to think about using BT to support SC visibility, traceability, and mapping. Boosting SC traceability enhances SC integration overall and considerably lowers the likelihood of reputational risk.

As a result, by highlighting weaknesses in the micro part of the supply chain, BT enables managers to implement stronger, more environmentally friendly, and more viable business procedures. It is significant to note that BT plays a critical role in reducing supply chain inefficiencies and disruption, as well as in helping a company establish SC integration and sustainability. All things considered, we advise businesses to use BT as a cornerstone strategy to enhance digital supply chain sustainability, integration, viability and mapping,

## 7. Conclusions

BT is an interesting technology with various benefits like cryptography, and transparency that has the potential to revolutionize many sectors. However, BT implementation in VCDSCs is still in its early stages and is hampered by several difficulties. As a result, the aim of this article was to identify and analyze the BT adoption barriers in VCDSC. It also develops a "causality diagram" that depicts the "cause-and-effect link" between the studied roadblocks and examines the results to provide practical and managerial implications. Managers face serious challenges because of potential barriers to BT adoption. Therefore, through an iterative development process based on different keywords related to the field of research and using the Boolean operators (AND/ OR). We have selected a list of barriers for SC while considering circular and viable concerns. However, from 22 barriers listed in figure 1, 14 barriers (selected using the AHP method) were studied and analyzed in terms of "cause/effect" interaction using the DEMATEL methodology.

The findings revealed that the most prominent influencing barriers to the effective implementation of the BT in VCDSC are "Data transparency", "Market competition", "Missing infrastructure", "Lack of standardization" and "Complex protocol" are "prominent barriers" that have an impact on a variety of other barriers. As a result, to achieve a successful deployment of BT in VCDSC, these barriers must be addressed first. Moreover, the main obstacle to SC mapping may be a company's capacity to gather accurate data covering the whole supply chain. An industry-level macro-map, which aids the company in determining the breadth and depth of a supply chain, can be one of the answers.

Our findings emphasize the crucial significance of Industry 4.0 barriers in deploying Blockchain in VCDSC, which is consistent with the technology adoption paradigm (Davis, 1989). The findings back up the idea that technological maturity, feasibility, and capability are all important barriers to overcome. In contrast to prior research, this study elucidates the mechanism for promoting CSC and integration in the implementation of BT, namely, enhancing circular management support models and ensuring viability performance. Besides, companies must create a thorough strategy for adopting new technologies. A business can assess if the newest technologies are appropriate for use in the company by developing such a plan. Adopting modern technologies continuously benefits the firm as well.

Despite its valuable insight for both theory and practice, there are certain shortcomings in this work that might be addressed in future studies. First, this research investigated 14 specific barriers to BT adoption. Other ones have still to be analyzed and investigated. Second, interactions in the initial matrix collected from the experts' team are likely to be unknown. Gray and fuzzy set theories can be also used to alleviate this confusion. Finally, the influence of Covid-19 on BT uptake has not been investigated in this study. As a result, future studies can look at how covid-19 outbreaks impact the use of BT in VCDSC.

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