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Implementation of blockchain – IoT-based integrated architecture in green supply chain

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Abstract

Purpose – Digital supply chains require nascent technologies like blockchain and Internet of Things (IoT). There is a need to develop a roadmap for the implementation of these technologies, as they require a huge amount of resources and infrastructure. The purpose of this paper is to analyze the challenges of implementing blockchain-IoT integrated architecture in the green supply chain and develop strategies for the same.

Design/methodology/approach – After a thorough literature survey of Scopus-indexed journals and books, 37 barriers were identified, which were then brought down to 15 barriers after confirming with industry and academic experts using the Delphi method. Using the total interpretive structural modeling (TISM) method and cross-impact matrix multiplication applied to classification (MICMAC) analysis, the barriers were modeled, and finally, strategies were formulated using a concept map to handle the barriers in the blockchain-IoT integrated architecture for a green supply chain.

Findings – This paper presents the research on barriers that can be considered for incorporating blockchain and IoT in the green supply chain. It was found from the TISM model that environmental concerns are Level-1 barriers and need to be addressed by developing appropriate technology and allocating funds for the same. An integrated ecosystem with blockchain and IoT is developed.

Research limitations/implications – The focus of this study was on the challenges of blockchain and IoT; hence, it is required to extend the research and find challenges for different industries and also analyze the criteria using other multi-criteria decision-making (MCDM) methods. Further research is required for the integration of blockchain-IoT with supply chain functions.

Practical implications – The transformation of a traditional supply chain into a green supply chain is possible with the integration of technologies. This research work and the strategies developed are useful to managers and practitioners working on technology implementation. Planning resources and addressing key barriers is possible with the concept maps and architecture developed.

Social implications – Green supply chain management (SCM) is gaining importance in industry as well as the academic sector due to government Policies and norms worldwide for reducing emissions and encouraging environment-friendly production systems. Incorporating blockchain and IoT in a green supply chain will further digitize and increase transparency in supply chains.

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Originality/value – We have done a categorization of all barriers based on the expert survey by academicians and industry experts from industries in India. The concept map helps in identifying possible solutions for the challenges and initiatives to be taken for the smooth integration of technologies in the green supply chain.

Keywords Green supply chain management, Blockchain technology, Internet of things, Concept map, Blockchain IoT integrated architecture (BIoT-IA), Total interpretive structural modeling (TISM)

Paper type Research paper

1. Introduction

A green supply chain is getting attention from industries due to policies at the global level for environment management. Investigations into green supply chains have gained momentum after 2000 (Saberi *et al.* (2018). Integrating environmental sustainability into the supply chain has become a necessary measure for the long-term competitiveness and operations of companies (Nulkar, 2014; Pimenta and Ball, 2015). Two important parameters of a green supply chain are traceability and transparency. Traceability deals with tracking of product right at its source and monitoring its existence throughout the life cycle. Transparency is required in green supply chains to have legal compliance and a credible value chain which also helps eliminate green wash (Chen, 2018).

Blockchain is progressively being applied in both academic and industrial perspectives (Almeshal and Alhogail, 2021; Tijan *et al.*, 2021). Blockchain is a digital ledger that can be used for transactions across the supply chain (Niranjanamurthy *et al.*, 2019; Kshetri, 2021). It consists of cryptographically linked blocks of transactions, which form a blockchain. IoT-based smart contracts are used for carrying out transactions. Blockchain positively affects organization performance by green supply chain (Jiang *et al.*, 2023). Wang *et al.* (2023) proposed a finance model for green supply chain for energy efficiency. Blockchain and IoT together give solutions to businesses that require the involvement of multiple parties. A basic principle of Blockchain is decentralized transparency which is in line with the circular economy concept. The major challenges are to implement this new technology which completely transforms the old supply chain and the issues associated with all transactions being visible to everyone on the supply chain (Khaqqi *et al.*, 2018).

In a sustainable supply chain context, Blockchain is being effectively adopted for society, environment and economy (Munir *et al.*, 2022; Senthil *et al.*, 2022). However, for effective adoption of Blockchain-IoT in sustainable supply chain organizations need to overcome barriers of inter and intra organization, system related and external (Saberi *et al.*, 2019). Multi-criteria decision-making (MCDM) techniques were used in understanding adoption of blockchain in green supply chain. Some of the prominent tools were interpretive structural model (Elhidaoui *et al.*, 2022), decision- making trial and evaluation laboratory (DEMATEL) (Biswas and Gupta, 2019), ISM-DEMATEL (Yadav *et al.*, 2020), mixed-method qualitative analysis (Saheb and Mamaghani, 2021), structural equation modeling (Choi *et al.*, 2020; Govindan *et al.*, 2023), Fuzzy AHP (Analytic Hierarchy Process)-Fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) (Öztürk and Yildizbaşi, 2020). However, the recent literature fails to address Blockchain-IoT for green supply chain (Rane and Thakker, 2020). To address this research gap, this study addresses following research questions (RQs).

RQ1. What are the challenges in the implementation of Blockchain and IoT in green supply chains?

RQ2. What is relationship amongst these barriers?

RQ3. What strategy formulation is required to overcome the barriers?

This paper analyses the barriers to the implementation of blockchain and IoT integrated architecture in a green supply chain. Section 2 gives Literature reviews of the Green supply chain, Blockchain and IoT in supply chains with real-life use cases and challenges in the implementation. In sections 3 and 4, the barriers are identified and analyzed using a structural modeling tool. Section 5 and 6 covers Discussion and strategy formulation with possible solutions for overcoming the barriers. Section 7 is for conclusion and future scope of research in the area of blockchain and IoT in green supply chain management (SCM).

2. Literature survey

Literature survey of peer-reviewed journals, technical articles and books was done to identify the challenges associated with Blockchain and IoT technologies. Literature survey is divided into four sections as discussed in Table 1.

2.1 Blockchain in green supply chain

Evolution of technology like Blockchain may take time and companies may have to use pilot structures to adopt blockchains (Niforos, 2017). Before adopting blockchain, organizations will have to analyze the risks associated with it and the opportunities that the technology may offer (Currents and Journal, 2017). Blockchain solutions in the automotive industry can be vital in tracking goods as they move from one point to another and minimizing fraudulent activities as it provides tracking of spare parts through the supply chain (Dorri *et al.*, 2017).

The environmental impact of supply chains includes issues like carbon emissions, resource depletion and ethical concerns related to sourcing practices (Rao and Holt, 2005). Blockchain is explored as a tool to address these challenges. Blockchain applications are studied for their potential in reducing the carbon footprint of supply chains (Wang *et al.*, 2023). Smart contracts and decentralized platforms enable automated verification of environmental certifications, ensuring that suppliers adhere to sustainable practices (Dagher *et al.*, 2018). This can contribute to lowering the overall environmental impact of the supply chain. Blockchain facilitates the efficient reuse, recycling and resale of products (Develo, 2018). This can lead to a reduction in waste and a more sustainable approach to resource utilization. Moosavi *et al.* (2021) have done detailed review of blockchain implementation in SCM and found that traceability and transparency are most evident advantages of Blockchain implementation.

Blockchain has some promising advantages as listed below.

(1) Blockchain enhances payment speed and makes a payment more affordable (Clauson *et al.*, 2018).

Time period	Search engines	Primary keywords	Secondary keywords Group 1	Secondary keywords Group 2
From 2000 to 2023	• Google Scholar • Science Direct • Springer Link • Emerald Insight • ACM Digital library	• Blockchain • Internet of Things/IoT • Green supply chain • Blockchain-IoT Integrated architecture	• Use cases • Total ISM • MIC MAC • SWOT • Concept Map	• Architecture • Ranking • Barriers • ISM • Hyperledger

Source(s): Authors' own work

Table 1.
Details of literature search

(2) It streamlines the process and promotes high security across the supply chain (Li *et al.*, 2017).

(3) Makes supply chain more transparent (Khan and Salah, 2018).

(4) All transactions and processes are managed in real-time with blockchain (Leng *et al.*, 2018).

(5) Tracks the goods at every link and stage of the process (Abeyratne and Monfared, 2016).

(6) Automated blockchain ensures there is no need for physical documentation and hence need for brokers and agents are reduced (Christidis and Devetsikiotis, 2016).

(7) Suppliers may be benefitted by blockchain as payments are faster and more secure.

(8) Pareto optimization of green supply chain (Wang *et al.*, 2023).

(9) Critical analysis and suitability evaluation of suppliers (Almeshal and Alhogail, 2021).

2.2 IoT in green supply chain

Supply chains are becoming competitive and technology is a valuable differentiator. Various parties and people are connected in a supply chain and for the whole ecosystem it is essential to have the data access of suppliers and buyers to give improved customer service and ensure product integrity and quality. It has become necessary to track shipments, delivery time and real-time data to comply with regulations of safety and security.

Industries are shifting to digital space with advanced solutions to supply chain problems (Reyna *et al.*, 2018). IoT device helps collect and utilize large database most efficiently. The major challenge lies with leveraging the data collected for prediction and optimization. Radio frequency identification (RFID), Wireless sensor networks, middleware, Cloud computing and IoT interfaces are key technologies in IoT. IoT enables agility and responsiveness so as to plan, control and coordinate the activities in supply chain (Chaudhari *et al.*, 2022). IoT is an enabler of industry 4.0 that leads to smart and sustainable products and services. Collaborative supply chain for data acquisition and intelligent systems to monitor and control sensors requires IoT for successful management. IoT leads to environmental and technological changes in complex and diverse situations and promotes sustainable smart business (Rane and Thakker, 2020).

The advantages and applications of IoT from literature are given below.

(1) IoT gives efficient utilization of resources with monitoring of resources (Abdel-Basset *et al.*, 2018).

(2) With interaction and communication amongst IoT devices, minimum human intervention is required (Chen, 2015)

(3) Large data collection is possible on IoT clouds with real-time access and storage of data (Khan and Salah, 2018).

(4) Automation is the key to saving time and IoT devices allow automating and controlling tasks with complete transparency in the process (Reyna *et al.*, 2018).

2.3 Use cases of blockchain-IoT

Table 2 gives use cases of Industry for Blockchain and IoT implementation in their supply chains. De beers, the diamond giant, trained all his miners for the blockchain technology for

Name of industry	Application of blockchain-IoT in SCM	Description	Benefits and remarks
De Beers – Diamond Industry Kshetri (2021)	Training the diamond miners before buying their diamonds	De Beers could track the source of their diamonds right from mine to the store. It is done by keeping the records of diamonds at each touchpoint and keeping real-time records of each transaction	De Beers gained additional supply and consumers got the assurance that the diamonds are free from defects
Maersk- Shipping company Eljazzar *et al.* (2018)	Logistics- Track shipping containers around the world	IBM and Maersk applied digital signatures, cryptography and hyper ledger to track each container across the global supply chain. More than 200 different interactions and communications were converted on blockchain	Mountains of paperwork was a big challenge to company and it got solved with integration of blockchain. Delays, Loss, Frauds in containers were eliminated
Provenance – Fishing Industry Kim and Laskowski (2018)	Tracking of fish caught by fishermen	Provence has used blockchain and smart tagging for tracking the fish which is caught by fisherman	Solved the challenges such as overfishing, fraud, lack of supervision, tremendous paper work and illegal transactions
Walmart- Online Hypermarket Casey and Wong (2017)	Tracking of produces from US and China	Walmart has used Blockchain for tracking Pork. Tracking of farm, temperature, storage conditions and logistics has helped to access authenticity of products and the expiry date	Time taken for tracking has reduced to few minutes with blockchain. This improved food safety and avoid contamination due to delays. Package authentication and tracking

Source(s): Authors' own work

Table 2.
Use cases of blockchain-IoT in SCM

authentication and purchase. Consumers are confident that the diamonds are defect free and pure because of the transparency and tracking of diamonds right from the source point. It also ensures no fraud in the supply chain.

Maersk is a Danish company into Container carriers and is considered as world's largest company with around 18%–20% of the market (Groenfeldt, 2017). Maersk has used blockchain applications in international logistics successfully. With blockchain, they have tracked the containers for Location, Temperature and storage conditions across the world. The cryptography involved would make it hard for the virtual signatures to be forged.

Blockchain pilot project was used by Provenance to trace fish in Indonesia. Provence could successfully track the fish caught by the fisherman to the consumer by use of Blockchain and smart tagging. Mostly the sustainable systems rely on reports and document. Blockchain has helped Provence overcome the issues such as Fraud and illegal fish transport and thus helps achieve sustainability claims.

Walmart has used Blockchain for tracking Pork and other food products. As food has less shelf life it is essential to track and verify the origin of the products. Blockchain ensured that Walmart could track the Food products within minutes as compared to days in past. The food can be called back if any contamination is found. Walmart is also planning to use blockchain for customer and courier authentication to measure different parameters related to containers and products.

2.4 Research gaps

As the implementation of Blockchain and IoT started recently, the long and short-term benefits are still not clear. Through extensive literature survey, some gaps are identified that needs to be addressed for success of Blockchain-IoT in green supply chains.

(1) There is a lack of convincing use cases that clearly show Blockchain's benefit over existing IT solutions.

(2) There is no roadmap available for blockchain, to ensure security and scalability in supply chain (Rane and Narvel, 2019; Chaudhari *et al.*, 2022).

(3) Research on challenges faced for implementing blockchain and IoT in green supply chain needs to be addressed (Thakker and Rane, 2018).

(4) A detailed analysis of all aspects for blockchain IoT implementation is required to be done.

(5) Architecture for implementation of Blockchain IoT is required for industries considering implementing it (Thakker and Rane, 2018).

(6) Analyzing challenges in green procurement for blockchain-IoT (Rane and Thakker, 2020).

2.5 Problem definition

Uncertain government policy for blockchain is the major hurdle for organizations that are looking to adopt these technologies. All stakeholders are not equally supportive of being part of such nascent technology. There are many other challenges associated with Blockchain such as scalability, confidence due to lack of success stories and data limits (Alabi, 2017). The technology is still not proven globally and needs more time for industries to adapt.

Internet of Things is more adapted as compared to Blockchain but still it has many barriers as there are no standards for incorporation. Integration of Blockchain and IoT is not done by many and it is still in research phase. It is required to find all the challenges associated with these technologies and develop a framework for implementation of Blockchain and IoT in green supply chains.

2.6 Research objectives

Though there is a strong encryption in blockchains, there are some cyber security concerns for general people to entrust their data to a blockchain solution (Bahga and Madisetti, 2016). The objectives of this research are as follows.

(1) Evaluate the barriers for implementation of Blockchain and IoT in green supply chains.

(2) Ranking of barriers and finding relationship amongst the barriers.

(3) Analysis of Blockchain-IoT implementation in GSC (Green Supply Chain) by doing SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis

(4) Development of architecture for implementation of blockchain and IoT

Figure 1 gives detailed flowchart of research methodology used for this research work.

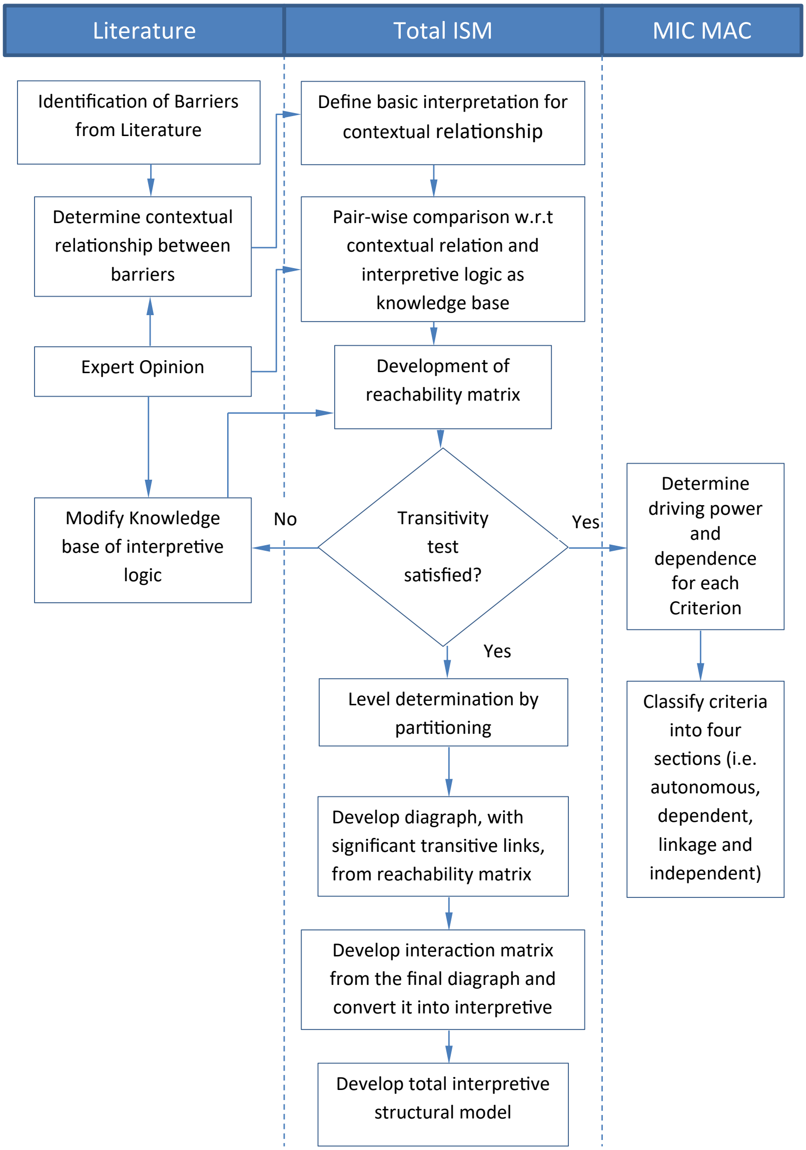


Figure 1.
Research methodology flowchart

Source(s): Authors' own work

3. Barriers for blockchain –IoT in green supply chain

A total of 50 experts were identified for the Delphi method out of which 30 members volunteered to participate and reply to data collection forms. They were mailed a questionnaire and the responses were received within a month.

Based on responses of experts and literature survey, 37 challenges were identified initially and later 15 barriers were considered as most critical for implementing blockchain and IoT in supply chains. Each barrier is described in brief along with the source in Table 3.

4. Modeling of barriers using total ISM (TISM)

Total interpretive structural modeling (TISM) is widely used for analysis where contextual relations are to be established (Dandage *et al.*, 2018). The method uses same model as ISM but also considers transitive relation between the parameters in addition to direct relation. This research focusses on modeling the barriers in the implementation of Block chain and IoT methods for Greening the supply chain. Final reachability matrix of ISM is given in Table 4 and TISM model of barriers is shown in Figure 2.

Literature survey and interviews with experts from industry and academia led to identification of 15 barriers. The questionnaire was designed and shared with experts from supply chain and consultancy to identify any discrepancy and finally it was sent to the respondent who agreed to fill the survey and was expert in the field. Appendix shows sample pairwise interpretive logic-knowledge base table for Barrier B1.

Delphi method was used for survey conduction as suggested by many researchers and found as best tool for data collection. More than 50 experts were contacted working in the area of supply chain, blockchain, Information technology and as consultants. Each expert was asked to give pairwise rating of 15 barriers. Delphi score is calculated as given below:

$$\text{Delphi Score} = [(\text{Lowest Score} + \text{Highest Score} + 4) \times \text{Average Score})]/6.$$

Cronbach's Alpha is usually used to test reliability of the questionnaire. Based on the pilot study the value of Cronbach's alpha, also known as α coefficient was found as 0.7998 and hence found acceptable as it is more than 0.7.

4.1 MICMAC analysis

MICMAC analysis is done to analyze the driving power and dependence of the barriers. Figure 3 shows four clusters representing all barriers as per their driving and driven powers.

Cluster A: Autonomous barriers- The barriers that have weak driving and driven power are in this cluster. B_1, B_{11}, B_{13} and B_{14} were found to be autonomous barriers and almost not related to the system.

Cluster B: Dependent barriers- B_3, B_9 and B_{10} barriers have weak driving power but strong dependence and are grouped as dependent barriers.

Cluster C: Linkage barriers- B_2, B_4, B_5 B_6 and B_7 barriers have strong dependence as well as driving power. They have strong impact on other barriers, for instance lack of roadmap and training B_5 and B_6 affects the barriers like lack of security and scalability.

Cluster D: Independent barriers- B_{12} and B_{15} barriers have strong driving power but weak dependence. They are considered as inhibitors and independent of other barriers influences.

4.2 SWOT analysis

An applied SWOT framework, may support companies by analyzing the opportunities of blockchain IoT. A simple SWOT analysis is done to get a detailed perspective of Blockchain and IoT in a green supply chain (Figure 4).

4.2.1 Strength. One of the strengths of Blockchain IoT integrated structure is Operational Efficiency as it makes information sharing very easy. Secure encryption and tamper-proof data storage is possible. It eliminates central authority of who has full access to the data as it

Sr. No	Barrier name	Description	Source
B1	High Energy consumption	Blockchain uses the proof-of-work mechanism and validates transactions. These calculations require large amounts of energy to power the computers solving the problems and a sizable amount to cool down the computers	Kshetri (2017), Reyna *et al.* (2018)
B2	Weak Legislation	The legislation is considered to have a high influence on strategy formulations of industries. There is no legal provision to ensure enforceability of smart contracts to avoid disputes among the transacting parties	Handfield and Bechtel (2002), Weber *et al.* (2016)
B3	High Initial investment	Establishing a system with Blockchain and IoT for entire supply chain needs huge investments in terms of equipment and updating the original system	Kshetri (2017). Reyna *et al.* (2018)
B4	Lack of Top management support	The amount of investments in SCM and relevant technologies depends on top management's attitude. Many authors have discussed the negative impact of lack of management's support to the implementation of new initiatives	Handfield and Bechtel (2002)
B5	Lack of Roadmap for continued blockchain innovation	New products and services are evolving based on blockchain transactions. As it's a new technology, there is no roadmap available on how it will get evolved in the future	Our contributed Barrier
B6	Lack of training	Digital supply chain requires all the employees to be trained in new technologies so that they don't become obsolete	Kshetri (2017), Reyna *et al.* (2018)
B7	Lack of Organizational Resources	Blockchain requires a complete shift to the decentralized network and hence requires all the organization's resources for its implementation	Zhao *et al.* (2016)
B8	Nascent technology	Blockchain-IoT is still in a nascent stage and will require some time to evolve completely. Resolving issues like transactions speeds and data limits are crucial in making its adoption worldwide	Yli-Huumo *et al.* (2016), Chung and Kim (2016)
B9	Scalability of technology	Blockchain is not able to support wide range of transactions and scalability is major concern for organizations	Kshetri (2017), Reyna *et al.* (2018)
B10	Data security concerns	In a public ledger like blockchain everyone can see all the transactions on a Blockchain network. Data security is main concern for the parties doing the transactions	Khan and Salah (2018)
B11	Lack of standards to ensure the interoperability of systems	Global standard of IoT communication protocol are required for smart objects and systems to eliminate sources of vulnerabilities throughout the SC nodes and links. It is required to find a way to integrate the existing system with the blockchain solution for interoperability of systems	Khan and Salah (2018)

Table 3.
Barriers in implementation of blockchain and IoT in green supply chains

(*continued*)

Sr. No	Barrier name	Description	Source
B12	Lack of sufficient digital skills	The technologies require high-end skill sets not easily available in employees. App development or understanding the data and software is difficult for inexperienced employees	Li *et al.* (2017), Reyna *et al.* (2018)
B13	Smart Contract Vulnerabilities	Hackers can access and use the data on smart contracts if security is not full proof	Khan and Salah (2018)
B14	Digital to Physical Link	Blockchain and the data stored in it exist only in the digital realm. Interfacing the data tracked in the blocks to the physical goods being traced requires other technologies	Banerjee *et al.* (2018)
B15	Management of Data	IoT collects lot of data and it is visible to everyone in the supply chain processes. It is difficult for organizations to handle and process this data	Khan and Salah (2018)

Source(s): Authors' own work

Table 3.

Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DP
1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	6
2	0	1	0	1	1	1	1	0	1	1	1	0	0	0	1	9
3	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0	6
4	0	1	0	1	1	1	1	0	1	1	1	1	1	0	1	11
5	0	1	1	1	1	1	1	0	1	1	1	0	0	0	1	10
6	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	12
7	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	12
8	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	14
9	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0	6
10	0	1	1	1	1	1	1	0	1	1	0	0	0	0	0	8
11	0	0	1	1	1	1	1	0	1	0	1	0	0	0	0	7
12	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	12
13	0	1	0	1	1	1	1	0	1	1	0	0	1	0	0	8
14	0	0	0	1	1	1	1	0	0	0	0	0	0	1	0	5
15	0	1	1	1	1	1	1	0	1	1	0	0	0	0	1	9
Dependence	4	10	11	15	15	15	14	1	13	10	8	5	6	1	7	

Source(s): Authors' own work

Table 4.
Final reachability matrix of ISM

is available globally for all supply chain partners and stakeholders. Real-time data access makes it convenient for all the users.

4.2.2 Weakness. Although several solutions are present, Scalability issues are prime challenge as there are too many transactions involved and system gets overloaded. Blockchain is mostly not modular hence an old encryption module cannot easily be replaced. A blockchain doesn't provide an immediate out-of-the-box exit strategy. There are Issues with Identification at entry point. High initial investment, Regulatory uncertainty, nascent technology and high Energy consumption are some weak points of blockchain and IoT.

4.2.3 Opportunities. The integrated structure gives lot of opportunities because it acts a platform for Big Data and analytic research. It gives back control to the user, e.g. instead of

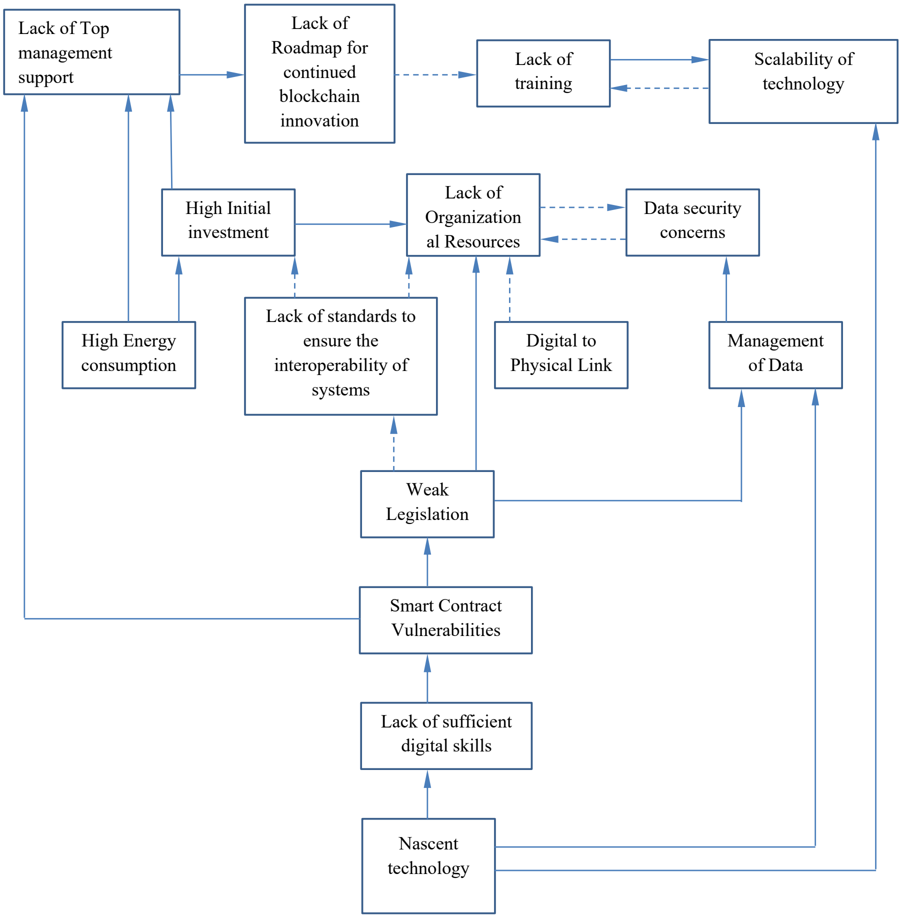


Figure 2. TISM model for barriers

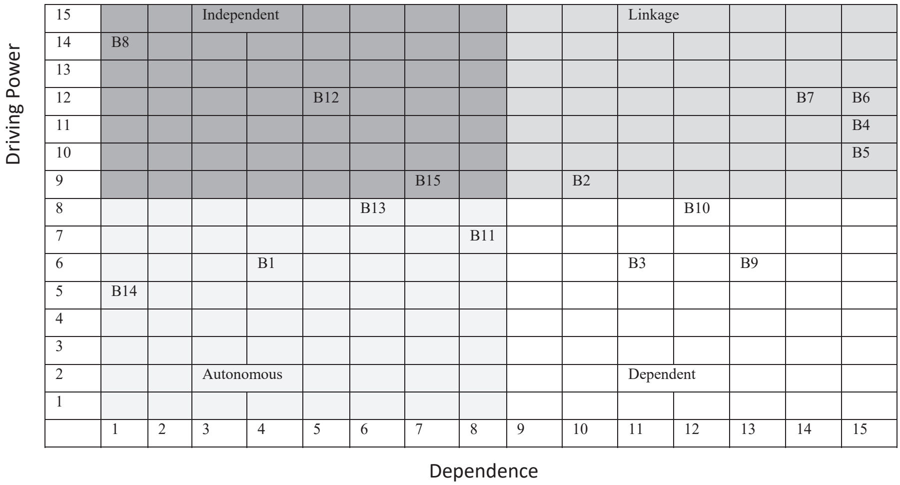
Source(s): Authors' own work

Google and Facebook using the data, one can control who gets access to your data. All these permissions will be stored on the blockchain. The world is becoming more digitized, so more people will accept the concept of blockchain in their daily lives. Other opportunities if the structure is cutting in IT and Processing Cost, Better security, use as Public or Private Register and Avoidance of Intermediaries.

4.2.4 Threat. Major threat of any new technology is that it may get misinterpreted (Eisenhardt and Graebner, 2007). Quantum computers (in the future) can decrypt data that are a big threat for blockchain and IoT. There is always the possibility of mining attacks and hacks. Scope of possibilities is overestimated and Commercial viability is overtaken by technological developments.

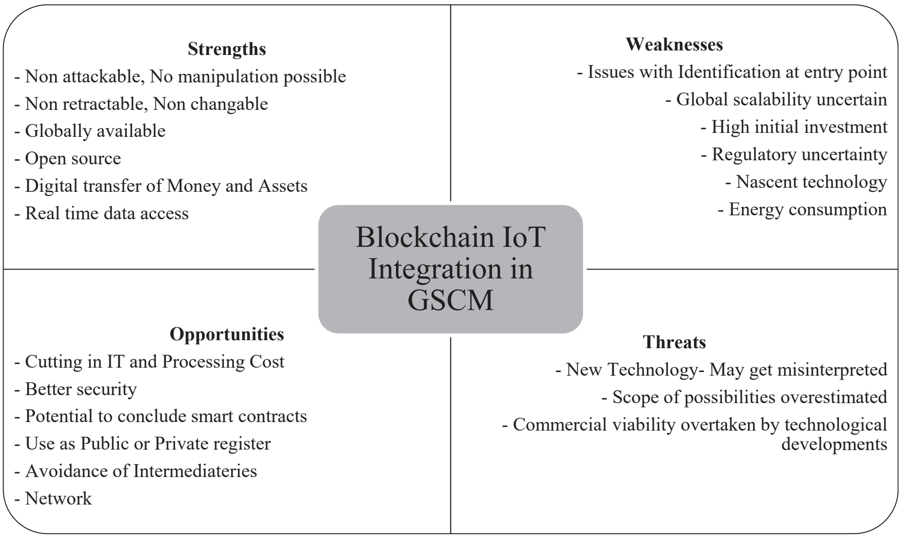
5. Results and discussion

Objective of this study is to analyze the barriers in implementation of BIoT-IA in a green supply chain. 15 barriers were identified about technical, Environmental, organizational and



Source(s): Authors' own work

Figure 3. MICMAC analysis of barriers



Source(s): Authors' own work

Figure 4. SWOT analysis

management issues in the implementation of integrated technologies like Blockchain and IoT.

The interpretive logic database was created for pairwise comparison of all barriers. The TISM model shows nascent technology (B_8) is the barrier which affects all other barriers which is also in line with the research findings of (Kim and Laskowski, 2018). SWOT analysis also shows nascent technology as a weakness for BIoT-IA implementation.

Digital expertise (B_{12}) in integration and functioning of Block Chain IoT architecture is not found easily. Miners are attempting around 450 thousand Trillion solutions per second in efforts to validate the transactions which requires high amount of computer power (B_1). There are cyber security concerns that need to be addressed before general public can entrust their data to a blockchain solution (B_{10}). The blockchain IoT applications offer solutions that require significant changes to existing system or complete change of existing system. This transition needs to be done by strong strategies developed by management (B_5). High energy consumption and high investment are weakness of the BIoT-IA structure that may be considered as opportunity for the management for developing cost cutting technologies and introducing open-source models.

Lack of organizational resources (B_7) is another barrier affecting the implementation of blockchain and IoT as these technologies require high investment and infrastructure. Managing large amount of information and mining large volume of data to provide useful services requires high power computers and architectures. Blockchain and IoT offer tremendous cost saving on transactions costs but they require very high initial investment (B_3).

MICMAC analysis shows that barriers nascent technology (B_8), lack of sufficient digital skills (B_{12}) and management of data (B_{15}) are independent barriers as they affect other dependent barriers like support of top management, consumption of high amount of energy etc. but are not influenced by other barriers.

Management and organizational barriers like Weak Legislation (B_2), Lack of Top management support (B_4), Lack of Roadmap for continued blockchain innovation (B_5), Lack of training (B_6), Lack of Organizational Resources (B_7) fall under linkage barriers. They get affected by all independent barriers and they also influence other barriers strongly.

Concerns like scalability (B_9), data security (B_{10}) and high initial investment (B_3) are falling in dependent category.

High Energy consumption (B_1), Lack of standards to ensure the interoperability of systems (B_{11}), Smart Contract Vulnerabilities (B_{13}) and Digital to Physical Link (B_{14}) are autonomous barriers.

SWOT analysis provides the roadmap for implementation of BIoT-IA for a greener supply chain by considering strengths of technologies like global and digital availability, secure and real-time system. There are some weakness and threats related to this nascent technology like: identifying entry point, investments, regulatory norms and lack of trust in technology due to no proven results yet available. But the opportunity available with BIoT-IA overcomes the threats and weakness as it provides a fully secure and safer model by implementation of smart contracts and avoiding intermediaries. The SWOT framework justifies the implementation of BIoT-IA in supply chain as there are tremendous opportunities to overcome all the threats and successful implementation of model.

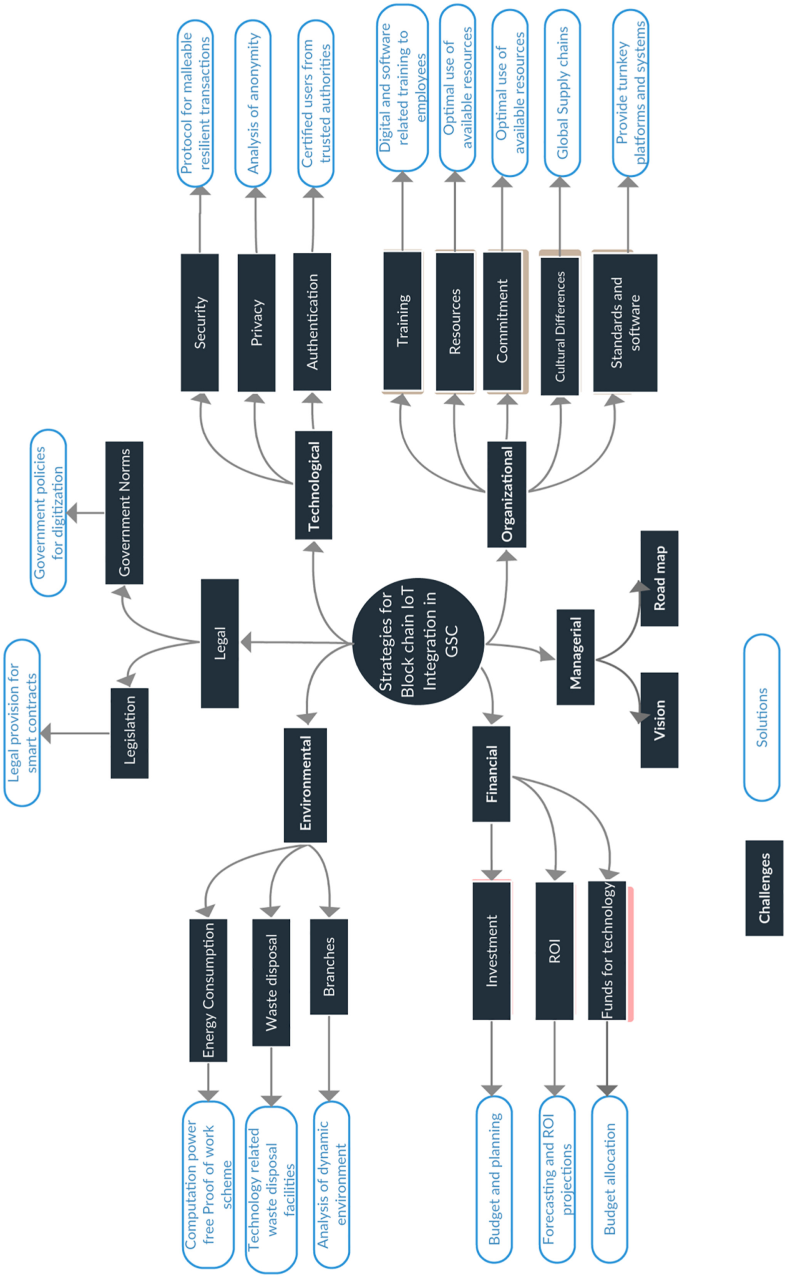
6. Strategies for BIoT-IA

Current manufacturing lacks accessibility to the procurement process. 31% of buyers cite finding the right manufacturing suppliers is a standard issue in the production process. The shift in business strategy within the revolution is driven by companies and manufacturers alike to streamline an efficient procurement and production process to reduce overhead costs and increase revenue.

6.1 Concept map for challenges and possible solutions

Concept map has been used as a strategic tool for showing the challenges faced in each criteria and possible solutions for the same (Figure 5).

High Energy consumption, Issues with waste disposal and other environmental challenges are faced while incorporating blockchain and IoT in a green supply chain.



Source(s): Authors' own work

Figure 5.
Possible solutions for blockchain-IoT integration in green supply chain

Computation power free proof-of-work scheme is suggested as a solution to reduce power consumption. Waste disposal facilities can be formed for efficient disposal of e waste.

Financial barriers include High Initial investment, less or no return on investment (ROI) and investments in technology. Blockchain offers high cost saving in transaction costs and time but requires high initial investment cost. The miners of blockchain network approximately do 400 thousand trillion solutions per second for validation of transactions. This requires high computer power consumption. These challenges may be addressed by Budget planning at early stages of Blockchain IoT implementation by allocating budget for the technology development. A forecasting tool can be used for finding ROI and other financial projections.

Weak Legislation and poor government policies are the hurdles from legal perspective. Smart contracts are used for legal documentation and profound policies for implementation laid by government will help in smooth transition from traditional to digital supply chains.

Lack of Top management support, Lack of Roadmap for continued blockchain innovation and Lack of training are barriers from managerial perspective. These barriers may be handled with training and knowledge sharing at all levels of a supply chain.

Technological challenges such as nascent technology, Scalability of technology, Data security concerns and Management of large amount of Data acts as barriers in successful implementation of high-end technologies such as blockchain and IOT. Use of protocols for malleable resistant transactions and ensuring certified users accessing the blockchain network can ensure safe use of technology.

6.2 Proposed blockchain-IoT integrated architecture for a green supply chain

Blockchain IoT integration can send information to ledgers for shared transactions and full proof records. It allows verification of transactions without central control and documentation. Blockchain records the transactions and the accountabilities of participants while IoT devices store the data. Transactions are stored on a node in hyper ledger. The agreement for transaction is performed using consensus to produce permanent record for the organization.

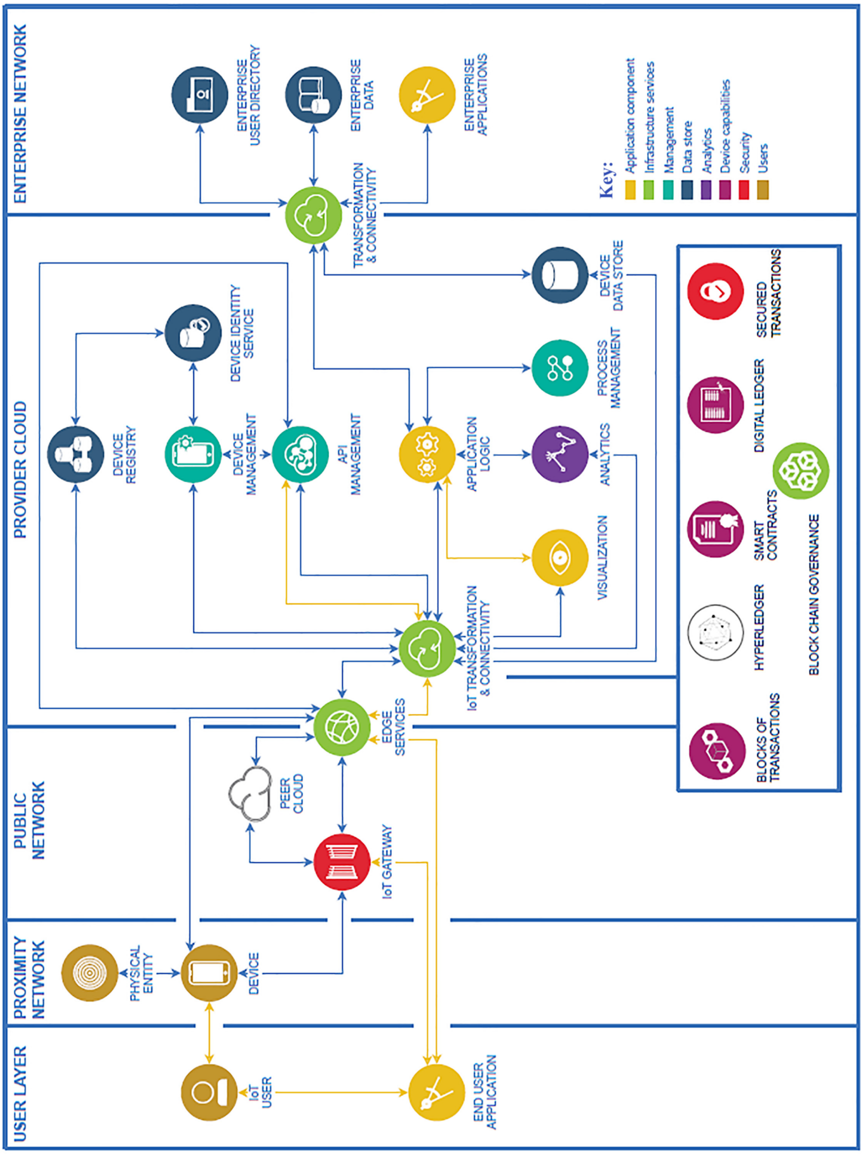
IoT platforms allow the devises to view blockchain transactions and store data at central level. IoT also helps in mapping of data and update it as per progress in supply chains. Real-time data can be sent to the concerned party to track the parameters like temperature or pressure of the objects.

The proposed architecture of Blockchain and IoT (Figure 6) shows the components and information flow. User layer and enterprise network are connected with cloud service. Transactions are secured with smart contracts and IoT cloud security services. Provider cloud network manages API (Application Programming Interface) and devices. End user applications and users on IoT are connected with IoT gateway and edge services.

6.3 Guidelines for practitioners

Implementing new technologies needs high-level commitment from the organization and employees. Blockchain and IoT do not have any available framework and application guidelines and hence managers and practitioners find it difficult to understand and apply them in practice. The guidelines developed below are to ensure the smooth implementation of technologies and create awareness in industries about challenges and solutions associated with these technologies.

(1) The practitioners are required to find the barriers and opportunities related to implementation of blockchain IoT Integrated Architecture. This will help in deciding whether the organization can implement the technology or may have to



Source(s): Authors' own work

Figure 6.
Proposed blockchain IoT integrated architecture

revisit the current position. This could be done by developing a SWOT framework as given in the research.

(2) Requirements of industries will vary based on the type and functioning of the industry and hence the technology requirement will also vary. Understanding the modules of Blockchain and IoT for creating phase wise plan of implementation will ensure the practitioners have first-hand learning.

(3) The architecture of Blockchain IoT integration is complex and has users as well as all stakeholders involved in the system. It is required to carry out information and material flow within the network to ensure that system is full proof and information is secure.

(4) Financial planning is a major step for technology implementation as it revamps the existing model and needs complete shift in terms of ledger, computer systems and associated software. Success stories and case studies of global competitors will help the practitioners in planning and execution.

(5) Recycling and reuse of components is essential element in greening the supply chain. Tracking the products right from source till end of life and also beyond that is required to complete the cycle. Including reverse logistics with IoT sensors will help the smooth and real-time tracking of material after the complete life cycle.

(6) Ranking and comparison of barriers in BIoT-IA helps identifying the topmost challenges to address and it also helps in finding relation between barriers. The managers can list the barriers relevant to the industry and plan for the methods to overcome them.

(7) User interface created in the architecture shows the involvement of customers and other stakeholders. Training is required for all the stakeholders on usage of the interface and smart contracts. Users should be conversant with the technology and features of the interface before technologies are implemented.

(8) Collaboration with suppliers as well as customers is the key to success of Blockchain and IoT in the industry. Trust among stakeholders and strong relation will ensure timely data sharing and information processing.

(9) Legal issues related to smart contracts and government policies on using them are still not clear to industries. Managers are required to evaluate the terms and conditions associated and take legal verification of the process.

(10) Green supply chain has prime focus on Environment friendly product and processes. The BIoT-IA helps with making the flow of supply chain information, green and sustainable and hence needs to be considered by supply chain mangers for sustainable supply chains.

7. Conclusion and recommendation

Blockchain integrates the system to work efficiently with the supply chain technology. This makes the supply chain lean and green. Identification of every component of the manufacturing industry is done right from the origin to avoid any frauds related to loans and double payments. IoT enhances the security of system by ensuring cybersecurity and data safety. But both techniques require resources and participation of all supply chain partners for successful implementation and to utilize full potential of the technologies.

There are many barriers in implementation of BIoT-IA in a green supply chain. 15 barriers related to technology, resources, management, finance etc. were identified and TISM analysis was done to find contextual correlation amongst the barriers. The transitive links showing indirect relation helps in identifying the effect of barriers on each other.

The present study deals with identification of barriers in implementation of Blockchain and IoT in green supply chain, analysis of the barriers using TISM and MICMAC methods, development of architecture for implementation of BIoT-IA in supply chain and also suggests strategies for practitioners for successful implementation. SWOT analysis gives a framework to consider strength, weakness, opportunity and threats before implementing new models like BIoT- IA. Further studies are possible for validation of the architecture based on actual industry implementation and the barriers may be revised further as per growth and implementation of Blockchain and IoT in supply chains.

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Appendix

Sr. No	Barrier	Paired comparison of factors	Y/N	In what way one barrier will influence/enhance the other? Give reason if yes
B1	High energy consumption			
	B1-B2	High energy consumption will influence or enhance weak legislation	N	
	B2-B1	Weak legislation will influence or enhance high energy consumption	N	
	B1-B3	High energy consumption will influence or enhance high Initial investment	Y	Because of high consumption of energy, more investment will be required for implementation
	B3-B1	High initial investment will influence or enhance high energy consumption	N	
	B1-B4	High energy consumption will influence or enhance lack of top management support	Y	Due to high cost of energy consumption, management may decide against the implementation of new technologies
	B4-B1	Lack of top management support will influence or enhance high energy consumption	N	
	B1-B5	High energy consumption will influence or enhance lack of roadmap for continued blockchain innovation	N	
	B5-B1	Lack of roadmap for continued blockchain innovation will influence or enhance high energy consumption	N	
	B1-B6	High energy consumption will influence or enhance lack of training	N	
	B6-B1	Lack of training will influence or enhance high energy consumption	N	
	B1-B7	High energy consumption will influence or enhance lack of organizational resources	N	
	B7-B1	Lack of organizational resources will influence or enhance high energy consumption	N	
	B1-B8	High energy consumption will influence or enhance nascent technology	N	
	B8-B1	Nascent technology will influence or enhance high energy consumption	Y	As the technology is new, there is still research going on for energy saving
	B1-B9	High energy consumption will influence or enhance scalability of technology	N	
	B9-B1	Scalability of technology will influence or enhance high energy consumption	N	
	B1-B10	High energy consumption will influence or enhance data security concerns	N	
	B10-B1	Data security concerns will influence or enhance high energy consumption	N	

(*continued*)

Table A1. Sample interpretive logic-knowledge base

Sr. No	Barrier	Paired comparison of factors	Y/N	In what way one barrier will influence/enhance the other? Give reason if yes
	B1-B11	High energy consumption will influence or enhance lack of standards to ensure the interoperability of systems	N	
	B11-B1	Lack of standards to ensure the interoperability of systems will influence or enhance high energy consumption	N	
	B1-B12	High energy consumption will influence or enhance lack of sufficient digital skills	N	
	B12-B1	Lack of sufficient digital skills will influence or enhance high energy consumption	Y	Miners may have to work more and use more computer power for transactions as they don't have required skillset at initial stages
	B1-B13	High energy consumption will influence or enhance smart contract vulnerabilities	N	
	B13-B1	Smart contract vulnerabilities will influence or enhance high energy consumption	N	
	B1-B14	High energy consumption will influence or enhance digital to physical link	N	
	B14-B1	Digital to physical link will influence or enhance high energy consumption	N	
	B1-B15	High energy consumption will influence or enhance management of data	N	
	B15-B1	Management of data will influence or enhance high energy consumption	N	

Table A1. **Source(s):** Created by authors

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