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Addressing Challenges: Adopting Blockchain in the Pharmaceutical Industry for Enhanced Sustainability

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Abstract: The growing importance of sustainability in organizational success, particularly in the pharmaceutical industry, underscores the need for leveraging technologies like blockchain to enhance sustainability indicators across environmental, social, and economic pillars. This study aims to identify and understand the challenges hindering the adoption of blockchain in the pharmaceutical sector for improving sustainability performance, addressing two research questions: the specific challenges faced by blockchain adoption in this context and the interdependencies among these challenges. Employing a two-step approach, the study compiles challenges through a literature review, refines them via expert opinions, and establishes their interrelationships using methodologies like Fuzzy Interpretive Structural Modeling (FISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC). The research contributes to unraveling the complex relationships and dependencies within the system, providing a structured framework for improved decision-making and strategic planning. It fills a literature gap by being the first attempt to outline driving and dependent factors related to the challenges of adopting blockchain technology for sustainability enhancement in the pharmaceutical sector, offering insights that can significantly impact brand image, company perception, and consumer value.

Keywords: blockchain; fuzzy-ISM; MICMAC; pharmaceutical industry; sustainability

1. Introduction

The significance of sustainability has been increasing within organizations, directly linked to organizational success, making sustainability an essential component of the business strategy [1,2]. Notably, a positive correlation has been observed between firm value and sustainability reporting [3]. For the pharmaceutical industry, a crucial sector on a global scale, it is a prized asset [4]. Businesses that comprehend how to leverage sustainability can gain support from investors, regulators, and consumers [5].

The pharmaceutical industry plays a fundamental role in achieving the United Nations' Sustainable Development Goals (SDGs), categorized into technological, ecological, and social dimensions [6,7]. Progress in the pharmaceutical industry is crucial for attaining the SDGs [8]. The intricate relationship between the SDGs and innovative progress in the pharmaceutical industry is evident in various domains, such as adopting the "green chemistry" approach. This contributes to reducing the carbon footprint, promoting responsible production and consumption, and mitigating climate change [9,10].

One approach to addressing sustainability challenges in the pharmaceutical industry involves digitalization. It plays a significant role in enhancing sustainability indicators across environmental, social, and economic pillars. Organizations not investing in digital strategies and enablers, such as blockchain, supporting a wide range of sustainability goals and metrics, risk a significant impact on brand, company image, and consumer value perception [11,5]. Especially, the integration of blockchain is expected to improve sustainability goals and impact all industries, creating

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opportunities for enhancing business processes and building trust in data sharing and records management in every sector [12].

In pursuit of the SDGs, blockchain stands as a pivotal enabling technology capable of fostering sustainable and secure solutions. With characteristics such as accountability, transparency, traceability, cyber-resilience, and enhanced operational efficiency in global partnerships, blockchain has the potential to significantly contribute to these objectives [13]. Consequently, multiple essential sustainability metrics within the pharmaceutical industry can be improved through blockchain adoption [14]. Despite its potential as a lever to help organizations enhance their sustainability performance, there are still obstacles to the widespread adoption of blockchain. Even as research on the challenges of adopting blockchain technology has been growing, previous studies have illuminated multiple obstacles to the adoption of blockchain, despite stakeholders' recognition of its potential capabilities [15]. Certain studies focus on particular countries and industries, whereas others have a broader scope. So, in adopting blockchain technology, it could be revealed that besides universally applicable challenges like awareness and understanding, there are also industry-specific as well as country-specific challenges such as certain laws and regulations [16-18]. Nevertheless, no empirical investigation has been conducted so far concerning the challenges linked to adopting blockchain for the purpose of improving sustainability within the pharmaceutical industry.

Building upon previous theoretical frameworks that address the challenges of adopting blockchain technology, this study aims to identify the specific challenges pertinent to the pharmaceutical industry to enhance sustainability performance and understand the interdependencies among these challenges. Thus, the study tackles two research questions:

RQ1 What challenges does the adoption of blockchain face in its effort to enhance sustainability performance within the pharmaceutical industry?

RQ2 What connections exist among the challenges related to the adoption of blockchain for the purpose of enhancing sustainability performance in the pharmaceutical industry?

The research methodology utilizes primarily a two-step approach, incorporating a three-phase decision framework. First, a compilation of challenges related to the adoption of blockchain technology in the pharmaceutical industry needs to be accomplished via a literature review. Subsequently, the list of challenges was refined through expert opinions by evaluating each challenge's significance using a Likert scale. To finalize the list, an analysis was conducted through statistical methods, and the reliability of the selected challenges was verified using a statistical test within the Statistical Package for the Social Sciences software by calculating the importance-index and Correlation Index Modified to Test Consistency (CIMTC). Ultimately, the interrelationship of these finalized challenges was established using the FISM and MICMAC methodologies.

As a result of the study, the challenges hindering and/or impeding the adoption of blockchain technology for enhancing sustainability performance will be revealed. Among the numerous challenges, those that play a significant role in this context will be identified. Additionally, various directly and indirectly related challenges will be structured into a comprehensive systematic model. This resulting model presents the problem's structure in a carefully designed pattern. This approach identifies relationships among specific challenges, allowing for a more precise description of the situation than when each isolated factor is considered. Thus, a structured framework for unraveling the complex relationships and dependencies within a system, thereby enhancing decision-making and strategic planning processes is provided.

The study closes the literature gap of understanding the dedicated challenges hindering pharmaceutical organizations from adopting blockchain technology to enhance their sustainability performance. Furthermore, it is the first attempt to outline the driving and dependent factors related to the challenges of adopting blockchain technology to enhance sustainability in the pharmaceutical sector.

2. Literature

2.1. Impact of blockchain and sustainability

Blockchain technology, as a decentralized transaction and data management system, offers a range of capabilities [19]. Its appeal lies in its capacity to facilitate transparent data sharing, optimize business processes, reduce operating costs, enhance collaborative efficiency, and establish a system that doesn't require explicit trust incorporation [20]. Additionally, it enables innovative approaches to green production, including the monitoring and storage of data related to pollution and environmental degradation. Real-time collection and analysis of green or low-carbon data further contribute to prompt decision-making [21]. These advancements present significant opportunities for progress in business, supply chain innovation, and sustainable development [22].

Widely recognized for its potential in enhancing supply chain sustainability, blockchain technology advances security, accountability, and efficiency [23,24]. The blockchain philosophy, guided by principles of democracy and decentralization, contributes to establishing more equitable supply chains. In this regard, it can be incorporated as a comprehensive strategy to achieve multifaceted objectives, such as supply chain mapping, sustainability, and integration [25]. Positioned as a potential Sustainability-Oriented Innovation, blockchain entails intentional changes to an organization's philosophy, values, products, processes, or practices with the aim of generating and actualizing social and environmental value alongside economic returns [26,27].

Furthermore, blockchain is advocated as a solution to current challenges, offering the potential to strengthen food security, mitigate fraud, ensure fair labor practices, and reduce waste and CO2 emissions [28,21]. Its potential to support the circular economy by lowering transaction costs, improving performance and communication throughout the supply chain, safeguarding human rights, and enhancing healthcare patient confidentiality and well-being is noteworthy [29].

The ways in which blockchain addresses social, economic, and environmental challenges highlight how the technology aligns financial performance with sustainability objectives. The potency for generating shared value is evident in the social and economic dimensions of sustainability. Enthusiasm for blockchain is evident in its current applications, offering new opportunities to enhance sustainability. Whether used as a tool, a mindset for sustainability, or both, blockchain can play a crucial role in overcoming challenges and enhancing the sustainability performance of organizations [30,31].

2.2. Sustainability and blockchain in the pharmaceutical industry

The decentralized nature of blockchain makes it more reliable, transparent, and traceable in business processes, where all transactions are consistent, stored, immutable, and distributed among all network nodes [32]. In the pharmaceutical industry, blockchain enables the achievement of the top five influential factors: monitoring, reliability, traceability, authorization, and real-time functionality [33].

Pharmaceutical supply chains differ significantly from typical supply chains, as any disruption in the pharmaceutical supply chain can have direct implications for patients' well-being [34]. A potentially effective solution to tackle the significant challenges in the pharmaceutical supply chain is blockchain since it offers traceability throughout the product's lifecycle by linking, disseminating, and transmitting data within an organization. This aspect is particularly crucial for highly regulated industries like pharmaceuticals [35].

Furthermore, various key participants, including manufacturers, wholesalers, and retailers are engaged in the production, transportation, distribution, and sale of medications traversing in a supply chain [36]. Thus, the need for a global system in global supply chains to swiftly alert people worldwide about the risks posed by substandard and falsified medical products is essential, since 50 percent of drugs consumed in developing countries are counterfeit [37,38]. Given that counterfeit medicines have become one of the world's most intricate and challenging issues, blockchain facilitates the monitoring of medicines at every stage of the supply chain [39,40].

The tracing feature of blockchain technology can also be leveraged regarding waste management, being a central challenge for the pharmaceutical industry [41]. It raises concern due to the potential threat it poses to human and environmental health. Given the associated risks, pharmaceutical waste cannot be treated like regular waste and necessitates special handling, whether originating from a hospital, clinic, pharmacy, or private household [42]. Blockchain technology has the potential to enhance waste management in the pharmaceutical industry by ensuring data privacy, compliance, cost-effectiveness, and expeditious trash collection and disposal. Traditional paper records have been replaced with electronic medical records, which are more readily available, secure, and shareable. In the pharmaceutical industry, blockchain can guarantee data consistency and security through a single source of truth, reliable verification procedures, and tamper-proof transactions. The transparency and tamper-proof nature of blockchain can facilitate drug monitoring, eliminate fraud, and enhance supply security [43].

While the adoption of blockchain technology holds significant promise for the sustainable development of the pharmaceutical industry, and despite the growing body of research on the challenges associated with its adoption, a comprehensive understanding of the potential challenges in adopting blockchain is still in the early stages [15].

2.3. Literature review

Employing a Systematic Literature Review (SLR) methodology, the existing body of literature was systematically explored. SLR offers a transparent and comprehensive search across multiple databases, ensuring the replicability and reproducibility of the available literature [44]. This widely adopted methodology, utilized by scholars such as Durach et al. (2017), Sansone et al. (2017), Wetzstein et al. (2016), and Sangwa and Sangwan (2018), aids in identifying, selecting, and reviewing relevant literature in the field of study. The selection process of the literature is displayed in Figure 1. The literature review was conducted by executing a Boolean search across several electronic databases such as Springer, IEEE Xplore, SCOPUS, ScienceDirect, Web of Science, Emerald, EBSCO, and Taylor & Francis. This search type was employed due to the presence of numerous interfaces within the search domain and its capability of limiting, expanding, and molding the results by incorporating additional elements into the search query [49,50]. The following search was performed and considered conference papers, journal articles, and book chapters published in English: "challenges of blockchain adoption" OR "challenges to blockchain adoption" OR "barriers of blockchain adoption" OR "barriers to blockchain adoption". A total of 65 studies were identified. In spite of the widespread anticipation of blockchain's influence on all sectors merely a few studies have examined the challenges involved in adopting blockchain technology [51]. The SLR indicates the existence of several studies exploring the challenges related to the adoption of blockchain. These studies cover perspectives specific to industries as well as those of a more general nature. Additionally, the researchers utilize a mix of qualitative and quantitative approaches to identify these challenges. It is important to highlight that only a small subset of studies delve into the interconnections among these challenges. Our SLR also emphasizes that there is a notable absence of prior empirical or quantitative assessments of the challenges associated with blockchain adoption, particularly in the context of improving the sustainability performance of the pharmaceutical industry.

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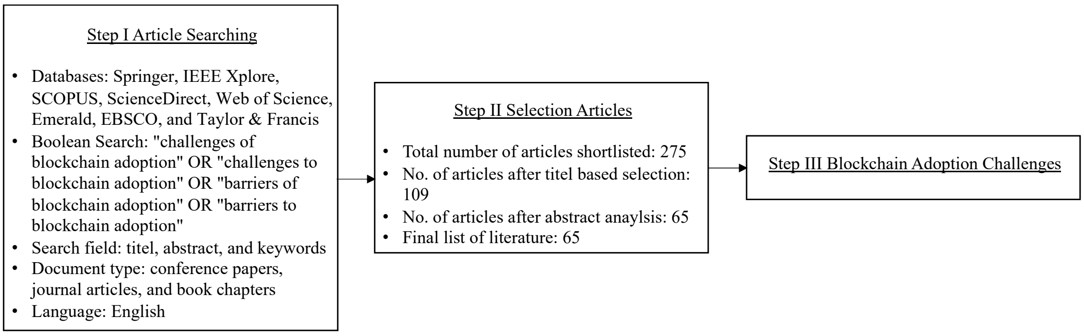

Figure 1. Literature selection process.

3. Methodology

A three-phase decision framework was employed to evaluate the obstacles associated with the adoption of blockchain technology aimed at enhancing sustainability in the pharmaceutical sector and to analyze the interrelationships among them, depicted in Figure 2.

In the initial phase, a comprehensive compilation of challenges related to the adoption of blockchain technology was discerned through an SLR and expert interviews. This compilation was then refined and finalized through statistical analysis. The reliability of the identified challenges was assessed using a statistical test within the Statistical Package for the Social Sciences (SPSS) software. Moving to the second phase, a FISM methodology was applied to establish connections among the identified challenges. Finally, in the third phase, a MICMAC analysis was conducted to categorize the challenges based on their driving power and dependence power.

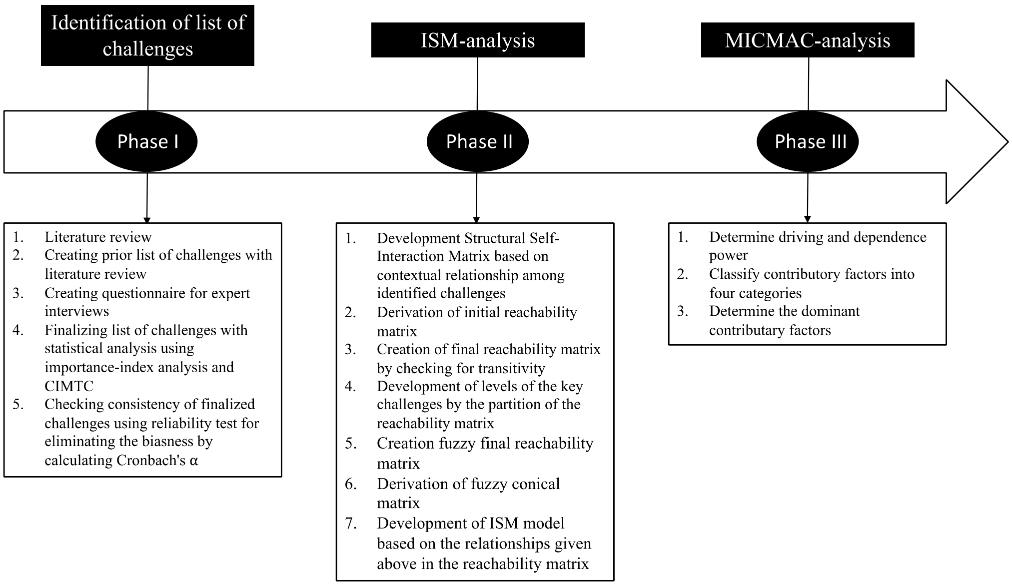

Figure 2. Three-phase decision framework.

3.1. ISM-analysis

Various MCDM techniques have been applied in barrier studies, with the Decision Making Trial and Evaluation Laboratory (DEMATEL), Interpretive Structural Modeling (ISM), and Analytical Hierarchy Process (AHP) methods being the most commonly used techniques for analyzing relationships between factors [52,53]. Although AHP is widely used for its simplicity, it may not effectively analyze complicated interdependencies among factors. DEMATEL and ISM, on the other hand, are favored for their ability to capture and represent interdependencies comprehensively [53]. Both ISM and DEMATEL serve as powerful structural modeling tools, offering a clear, hierarchical representation of the relationships among factors [54].

DEMATEL is primarily utilized for comprehending and illustrating the direction and strength of cause-effect relationships, both direct and indirect, among various criteria [55,56]. It enhances the understanding of complex issues and helps identify practical solutions within a hierarchical structure. DEMATEL is widely recognized and employed as one of the most effective models for visualizing and addressing intricate interconnections among various factors, capturing the intensity of influence on a Likert scale (e.g., 0-4) [56].

ISM is employed to organize dissimilar and directly or indirectly related factors or components in various cases. This method relies on multiple independent expert opinions to determine how factors are interrelated, resulting in the creation of a structured model. It is a modeling approach that develops diagram models of complex factor interactions categorized into four possible hierarchies, enabling clear and precise inferences in the given context. ISM is a valuable tool for transforming unpredictable problems into well-defined models that can be effectively communicated, representing the relationships and overall structure through a digraph model. This technique has found applications in solving complex real-life problems across different industrial settings, such as analyzing barriers in reverse logistics and understanding the drivers of green supply chain management. Moreover, it has been adopted as a methodology by numerous researchers [57-59].

To demonstrate the intensity of relationships between variables, Saxena and Vrat adapted ISM in 1992, resulting in the creation of Fuzzy Interpretive Structural Modeling (FISM). While ISM primarily considers variables as interconnected, FISM delves deeper into the strength of these connections. FISM operates on the premise that relationships between variables exhibit variability. Unlike ISM, which employs precise and definite values, FISM acknowledges that certain aspects of elements cannot be assigned crisp, exact values. This is because the outcomes are contingent on the preferences of decision-making experts. Therefore, fuzzy logic is considered a more practical approach for solving problems with inherent uncertainties, especially when multiple decision-makers are involved [60]. One could argue that FISM offers greater advantages compared to DEMATEL and ISM due to its ability to introduce rationality through the consideration of mutual relationships [61]. In this paper, FISM is applied to enhance the rationality of the ISM model in evaluating the relationships among system units. The precise procedures are outlines as follows:

1. Identification of the challenges of the concerned approach
2. Establishment of a contextual relationship among challenges through expert survey.
3. Creation of Structural Self-Interaction Matrix (SSIM) based on the contextual relationships between variable pairs.
4. Development of reachability matrix from the SSIM and check for transitivity.
5. Partition of the final reachability Matrix into different levels.
6. Creation of fuzzy conical matrix.
7. Development of FISM model based on the relationships given above in the reachability matrix [62,63].

3.2. MICMAC-analysis

MICMAC is a method that utilizes matrix multiplication properties and is used for the purpose of classification and examination [64]. It is employed to explore both the driving force and dependency of challenges [65]. The primary objective of MICMAC analysis is to evaluate and classify variables of interest according to their influence and dependency, resulting in their categorization into four groups: autonomous, dependent, linkage, and independent [66].

Characteristics associated with autonomous clusters exhibit weak influence and dependency. These attributes distinguish themselves within the model, characterized by a sparse yet impactful network and have minimal impact on the system. The absence of elements within autonomous clusters emphasizes the importance of all factors, necessitating comprehensive attention from practitioners [67]. The challenges categorized as dependent exhibit relatively low driving force but demonstrate a notable reliance on other barriers [68]. Elements identified as independent possess limited influence but significant dependency, relying on external factors and deserving increased

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consideration. Elements showing substantial dependency may also concurrently exhibit linkage due to their strong influence [69].

4. Research and data analysis

4.1. Data collection

MICMAC of the final literature list, developed as outlined in section 2.3, revealed 24 challenges related to blockchain adoption. The details, encompassing challenge titles, descriptions, and associated references, are comprehensively presented in Table 1.

Table 1. List of challenges and description of blockchain adoption.

No.	Challenge	Description	References
1	High costs of blockchain investments	Organizations can incur significant costs, particularly during the initial adoption phase, as they may need to develop software, including encryption and tracking technologies, and invest in additional hardware to establish blockchain-based operating systems. Moreover, while current blockchain usage is free, as adoption increases, subscription fees might be introduced due to network saturation, like other technology adoption scenarios.	70,71,72,73,15,74,75,18,77, 76,78,79,80,81,82,21,83,84, 8,85,86,87,88,89,90,91,92, 93,94,95,96,97
2	Lack of regulatory framework	If proper governmental regulations (data security and privacy laws) are not put in place, the widespread adoption of blockchain will remain hindered.	15,62,18,77,98,76,78,99,89,9 3,79,80,81,100,83,8,101,,90, 93,102,95,103,104,105,106
3	Lack of management support	Effective support from senior management is essential for the successful implementation of any sustainability initiative. This is especially true for the adoption of technology, where organizational leadership plays a crucial role.	75,78,89,107,108,21,84,8,10 1,106,109,90,91,92,110
4	Lack of security	Issues related to security can lead to data vulnerabilities, hacking risks, loss of confidentiality, reputation damage, regulatory non-compliance, and reluctance to adopt the technology. These issues collectively can hinder the adoption of blockchain in business settings.	111,70,112,73,15,75,18,77,7 8,99,89,93,79,105,113,100,2 1,103,83,84,8,101,85,87,106, 114,91,92,95
5	Difficulty in changing organizational culture	The adoption of blockchain technology results in the alteration or evolution of the existing organizational culture. Organizational culture encompasses norms related to work environment and suitable conduct within the organization.	111,100,21,103,84,109,90
6	Lack of standardization and homogeneity	Standardization has the potential to enhance efficiency, particularly through features like smart contracts, and it specifies transaction structures, validation, and security within the blockchain network. Without established standards, corporate hesitation is unlikely to diminish, and standardization can also break down technical silos, aligning with the blockchain's core aim of dismantling information silos and enabling horizontal integration.	111,75,18,78,79,82,85,86,91, 96,97
7	Degree of immutability	Immutability can create challenges when it comes to data accuracy, regulatory compliance, and adaptability since once data is recorded in a blockchain, it cannot be easily altered or deleted. While this is a key feature for security and trust, it can be problematic if errors are made or if there's a need to update information. The immutability feature can also pose legal and regulatory challenges.	111,70,75,80,21,8,89,114,91, 92,93
8	Lack of interoperability	Interoperability refers to the capability of different blockchain networks or systems to communicate and share data seamlessly. When interoperability is lacking, efficient data exchange between networks is prevented due to fragmented landscapes as well as a smooth transfer of assets and data across platforms is hindered. This siloed approach limits innovation, increases complexity, and can result in vendor lock-in since one may be dependent on a single blockchain platform.	111,70,71,112,15,62,18,77,9 8,76,78,79,80,113,82,21,115, 103,105,84,85,89,91,92,96

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9	Lack of resources	The complexity of blockchain may demand a significant investment of time and resources for companies to become proficient, while the expenses associated with hiring blockchain experts can be exceptionally steep due to high demand in the field.	111,112,18,98,80,108,21,103,83,82,84,101,85,89,90,91,93
10	Lack of governmental support and regulations	Despite the increasing number of countries considering initiatives to embrace Distributed Ledger Technology (DLT) and blockchains, tangible support from governments - such as incentives to adopt blockchain or laws that concern data sharing -remains limited and uncertain at this juncture.	111,75,18,77,98,103,99,93,79,80,108,113,100,82,21,103,104,83,107,84,101,85,87,89,91,92,93,97,110
11	Lack of market acceptance	The market's uncertain stance on accepting the technology and its associated products acts as a deterrent for managers when contemplating the risk of such investments and leads to trust issues among the stakeholders	111,15,17,75,18,99,89,93,107,80,108,21,82,8,85,86,88,106,90,91,92,102,95,96,24
12	Lack of scalability	The restricted block size in blockchain technologies has led to scalability challenges, with Bitcoin's block size of 1MB allowing just 7 transactions per second. Scalability affects the ability to handle growing transactions, while slow speeds hinder real-time processing. These limitations can impede adoption in various sectors and discourage investment in blockchain projects.	111,70,71,73,15,18,79,80,105,113,82,103,8,101,85,91,92,93
13	Lack of maintenance and management	Without regular maintenance blockchain networks experience slower transaction speeds and reduced efficiency leading to performance degradation. Ignoring security updates exposes the blockchain to exploitation by malicious actors, compromising data security and can lead to compatibility issues with newer systems. Furthermore, inadequate management can introduce errors, eroding the trust in the immutability of blockchain data and result in unexpected downtime, disrupting operations. Leading to users losing trust in poorly maintained blockchains, impacting adoption.	111,70,71,112,72,18,75,15,76,105
14	Lack of technology expertise and skills	Without a solid grasp of blockchain's intricacies, there's a higher likelihood of poorly designed or executed blockchain projects, resulting in suboptimal outcomes leading to reluctance in adopting blockchain solutions due to perceived risks. Furthermore, organizations may struggle to formulate effective strategies around blockchain integration without a clear understanding of how the technology aligns with their goals, including employee training.	111,70,71,112,72,15,75,18,98,76,79,108,113,81,100,82,21,103,83,107,80,8,101,85,89,109,91,92,94,95,97
15	Lack of data privacy	Since blockchain transactions are recorded on a public database accessible to anyone, it generates a setting that gives rise to privacy concerns for this technology.	70,112,73,15,75,18,77,98,78,80,105,108,113,81,100,82,21,103,83,79,84,85,90,114,91,92,95,96,24
16	Lack of validation	Due to limited piloting, insufficient validation could impede the adoption and utilization of blockchain technology.	70,71,108,82,21,115,83,105,89
17	Costs of latency	Given the inherent structure of the architecture, which requires the synchronization of all blocks within the chain for any new additions, this process could be resource-intensive, particularly in the case of extensive blockchains. This computational demand might pose a potential hindrance to implementation	70,18,79,80,101,85,93
18	Lack of collaboration and network establishment	Setting up a blockchain network system necessitates the participation and conviction of all involved parties that blockchain offers value to them. Moreover, achieving cooperation, communication, and coordination during the implementation process presents challenges.	15,73,18,98,76,100,21,115,104,84,85,109,90,114,,91,102,24
19	Lack of maturity	Computing processing power Blockchain is slow in operation. The restricted block size in blockchain technologies has led to scalability challenges, with Bitcoin's block size of 1MB allowing just 7 transactions per second. Scalability affects the ability to handle growing transactions, while slow speeds hinder real-time processing. These limitations can impede adoption in various sectors and discourage investment in blockchain projects.	111,75,18,98,78,99,89,93,80,113,21,104,82,84,8,106,90,114,91,92,93,95
20	Uncertain financial and	Blockchain mining consumes substantial energy for complex computations. Computers used for mining consume more energy than rewards. Expanding	81,100,82,103,83,99,79,84,8,90,95,74,18,89,92

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	environmental benefits	processor racks use energy comparable to lighting a megacity. Blockchain-based instruments' rising value attracts miners, yet increased rewards don't always lead to higher economic gains. Scalability issues worsen sustainability challenges. Proposed efficient hardware like Application Specific Integrated Circuits lags in large-scale production.	
21	Lack of employee acceptance	Employee acceptance hinges on multiple factors. Performance Expectancy gauges if the system aids job performance. Social Influence considers others' views on system use. Facilitating Conditions assess support for system use. In supply chains, transparency involves how information is conveyed to stakeholders. These factors shape employee system acceptance.	17,75,8,88,109,91,97
22	Reluctance to change business processes	Due to the broad applicability of blockchain across extensive and varied networks involving numerous stakeholders, be they individuals or institutions, its integration demands a specific level of expertise, time, and human resources. This could potentially lead companies and network participants to be hesitant about altering their business processes.	81,100,103,83,82,99,79,84,8, 101,85,95
23	Unclear responsibilities	While advocating for a decentralized database has its merits, there are instances where this kind of network can have drawbacks. Due to the distribution of data among participants in a blockchain, with equal footing depending on the permission type, the level of accountability among parties becomes ambiguous.	81,99,95
24	Lack of awareness	Customers' lack of awareness about blockchain and its diverse applications necessitates education on its features and implications for data ownership, access, and privacy. This education can boost blockchain adoption by companies and enhance the industry's social sustainability for customers.	111,106,83,21,84,92,95

For the evaluation of these challenges, quantitative data was required for the MCDM utilized in this study. An online questionnaire was deemed more suitable than alternative survey methods such as focus groups, workshops, or interviews due to its cost-effectiveness, automated data input and storage, broader coverage of the target group, reduced survey completion time, greater respondent availability, and consequently, higher response rates [116]. Between September and October 2023, the online questionnaire was distributed to selected respondents, encompassing companies in the pharmaceutical industry, consulting firms, software companies, and academics. The emphasis was on engaging respondents with comprehensive and trans-disciplinary knowledge to avoid biases towards specific obstacles, excluding individuals with expertise solely in pharmaceuticals, sustainability or blockchain.

Selection criteria mandated that experts should possess a background in the pharmaceutical industry, expertise in sustainability, and practical knowledge of blockchain. Additionally, experts from various companies and departments were included to ensure access to a diverse range of information, thereby augmenting the reliability of the data. A total of 65 experts were invited to participate, with 18 consenting. The selected experts' background information is outlined in for 21 challenges and is given in Table 2.

Table 2. Experts' background information.

No.	Gender	Highest education	Industry	Expert profile	Country	Experience in years
1	Male	MBA	IT	CIO	India	23
2	Male	Master	Pharma	Data Tech System Owner	Spain	12
3	Female	MBA	IT	Healtcare & Pharma Consultant	Switzerland	11
4	Male	PhD	IT	Director	United States	15
5	Male	MBA	IT	Supply Chain Expert	UK	25
6	Male	Master	Pharma	Managing Director	Luxembourg	15
7	Male	Master	Pharma	CEO	France	11
8	Female	MBA	Pharma	Data Privacy Senior Associate	Germany	11

9	Male	Master	IT	Blockchain Scientist	Germany	10
10	Male	MBA	IT	Supply Chain Expert	Germany	20
11	Male	PhD	IT	Chief Product Manager Life Sciences	Germany	30
12	Male	MBA	IT	Managing Director	India	27
13	Female	Master	IT	Business Process Consultant	Canada	17
14	Female	Professor	Academic	Professor	Italy	30
15	Female	MBA	IT	Managing Director	United States	20
16	Male	PhD	Pharma	Managing Director	Canada	28
17	Male	MBA	IT	Digital Supply Chain Manager	Turkey	25
18	Male	Professor	Academic	Associate Research Director	Singapore	16

While the literature lacks consensus on the optimal number of experts in a judging panel, it is suggested that the expert group should ideally comprise 6 to 25 individuals [117]. A decision-making approach involving a small number of experts can be effective if each expert possesses over ten years of experience [118]. The ISM method in particular is very suitable for use with a relatively small number of experts [119]. Moreover, previous studies employing the ISM methodology have reported the participation of experts ranging from 5 to 15 [120-122]. To enhance the reliability of expert assessments, a series of online presentations were conducted to clarify the study's objectives. Furthermore, experts were provided with a comprehensive guideline explaining each challenge. The final questionnaire underwent testing with a small sample of experts who not only contributed to the definitive list of barriers but also provided insights into the final survey format. This ensured the survey was concise, the definitions were comprehensive, and the questions were clear and easily comprehensible.

4.2. Data analysis using statistical tools

MICMAC To identify a cluster of closely related challenges for more in-depth analysis, statistical techniques, specifically the importance-index analysis and CIMTC, are applied. CIMTC quantifies the Pearson correlation coefficient between an individual item's score and the sum of scores for the remaining items. Items showing weak correlation (CIMTC values below 0.3) with other items are excluded from further investigation [123].

Table 3 presents a comprehensive statistical overview, including CIMTC values, regarding the barriers encountered in the adoption of blockchain in the pharmaceutical industry. It is evident that certain challenges, such as the “Difficulty in changing organizational culture”, “Lack of maturity”, and ”Uncertain financial environmental benefits”, exhibit CIMTC values below 0.3. Consequently, they are not considered for analysis.

The remaining 21 challenges display CIMTC values ranging from 0.4126 to 0.85410, making them suitable for further examination in this study. The survey data reveals a significant mean value, with a minimum of 2.8333 for all measures and a maximum standard deviation of 1.5811. This indicates that the data collected underscores the substantial significance of all the challenges identified for the adoption of blockchain in the pharmaceutical industry.

Additionally, the Importance-index analysis is utilized to assess the strength of expert opinions collected through the questionnaire survey. Numeric scores are transformed into relative importance indices using the formula provided in the equation below:

$$Importance\ index\ (I_x) = \frac{\sum_{i=1}^{5} p_i\, x_i}{5\ \sum_{i=1}^{5} x_i} \tag{1}$$

Table 3. Importance-index analysis, challenges statistics and CIMTC.

No.	Challenge code	Challenges of blockchain adoption in the pharmaceutical industry	Mean	Standard Deviation	Importance Index	CIMTC
1	Ch_1	High costs of blockchain investments	3.1111	1.2783	0.6222	0.5060
2	Ch_2	Lack of regulatory framework	3.6667	1.0847	0.7333	0.6601
3	Ch_3	Lack of management support	3.9444	1.0556	0.7889	0.5236

4	Ch_4	Lack of security	2.8889	1.4507	0.5778	0.7194
5	Ch_5	Difficulty in changing organizational culture	3.0556	1.3492	0.6111	0.2583
6	Ch_6	Lack of standardization and homogenity	3.1111	1.3235	0.7667	0.4913
7	Ch_7	Degree of immutability	3.6667	1.4142	0.6222	0.7945
8	Ch_8	Lack of interoperability	3.6111	1.0922	0.7444	0.6198
9	Ch_9	Lack of resources	4.000	1.3720	0.7111	0.8437
10	Ch_{10}	Lack of governmental support and regulations	3.3333	1.0290	0.7778	0.7332
11	Ch_{11}	Lack of market acceptance	3.0000	1.2367	0.6778	0.7307
12	Ch_{12}	Lack of scalability	3.2222	1.3086	0.5778	0.6181
13	Ch_{13}	Lack of maintenance and management	3.3333	1.3284	0.6444	0.7692
14	Ch_{14}	Lack of technology expertise and skills	3.1667	1.5811	0.7000	0.8541
15	Ch_{15}	Lack of data privacy	3.1667	1.2005	0.5889	0.4668
16	Ch_{16}	Lack of validation	2.8333	1.1504	0.6556	0.6219
17	Ch_{17}	Costs of latency	3.1667	1.2485	0.5778	0.6527
18	Ch_{18}	Lack of collaboration and network establishment	3.7222	1.3198	0.6667	0.6464
19	Ch_{19}	Lack of maturity	3.9444	0.9984	0.7222	0.1380
20	Ch_{20}	Uncertain financial and enviromental benefits	2.7220	1.1785	0.7556	0.2942
21	Ch_{21}	Lack of employee acceptance	3.1667	1.1504	0.5556	0.6152
22	Ch_{22}	Reluctance to change business processes	3.1667	1.0432	0.6667	0.8038
23	Ch_{23}	Unclear responsibilities	3.7222	0.9583	0.6333	0.4215
24	Ch_{24}	Lack of awareness	3.7222	1.2744	0.7222	0.4126

In the equation, p_i represents a constant that signifies the weight assigned to i, x_i represents a variable denoting the frequency of responses for i which takes values from 1 to 5. The importance index spans from 0 to 1 and is categorized into five clusters to signify the respondent's rating, as depicted in the equation below:

$$\begin{aligned} &\text{Very important: } 0.8 < I_x \leq 1.0 \\ &\text{Important : } 0.6 < I_x \leq 0.8 \\ &\text{Preferred : } 0.4 < I_x \leq 0.6 \\ &\text{Less important : } 0.2 < I_x \leq 0.4 \\ &\text{Not important: } 0.0 < I_x \leq 0.2 \end{aligned} \tag{2}$$

The analysis of the importance index for challenges in blockchain adoption was conducted using Equation (1), and the results are presented in Table 3. These results were compared against the threshold values outlined in Equation (2), leading to the conclusion that all barriers to blockchain adoption in the pharmaceutical industry are considered significant, as their importance index is above 0.2. In total, 16 barriers are classified as important, with an importance index exceeding 0.6 but less than 0.8, while the remaining five challenges are considered preferred, with an importance index above 0.4 but less than 0.6. The statistical analysis yields a roster of 21 established challenges. These confirmed challenges, as utilized in this study, are listed in Table 4. Thus, RQ1 has been answered.

Table 4. Final list of challenges.

No.	Challenge code	Challenges of blockchain adoption in the pharmaceutical industry
1	Ch_1	High costs of blockchain investments
2	Ch_2	Lack of regulatory framework
3	Ch_3	Lack of management support
4	Ch_4	Lack of security
5	Ch_5	Lack of standardization and homogenity
6	Ch_6	Degree of immutability
7	Ch_7	Lack of interoperability
8	Ch_8	Lack of resources
9	Ch_9	Lack of governmental support and regulations

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10	Ch_{10}	Lack of market acceptance
11	Ch_{11}	Lack of scalability
12	Ch_{12}	Lack of maintenance and management
13	Ch_{13}	Lack of technology expertise and skills
14	Ch_{14}	Lack of data privacy
15	Ch_{15}	Lack of validation
16	Ch_{16}	Costs of latency
17	Ch_{17}	Lack of collaboration and network establishment
18	Ch_{18}	Lack of employee acceptance
19	Ch_{19}	Reluctance to change business processes
20	Ch_{20}	Unclear responsibilities
21	Ch_{21}	Lack of awareness

To mitigate bias, the consistency of the confirmed blockchain adoption challenges was assessed through a reliability test conducted in SPSS software version 24. Data reliability was assessed by employing the Cronbach's alpha method. A Cronbach's alpha value closer to 1 indicates a higher level of internal consistency reliability [124]. In this study, the alpha coefficient, with a value of 0.9211 exceeded 0.70, indicating its reliability and signifying strong internal consistency [125].

4.3. FISM-analysis

In the next phase, a comprehensive model has been constructed utilizing the FISM approach to ascertain the interconnected relationships among these factors within the Indian healthcare industry. The steps leading to the evolution of the model are given in 3.1.

4.3.1. Creation of Structural Self-Interaction Matrix

For this specific research, 18 experts from the pharmaceutical sector were invited to establish the interrelationships among variables influencing blockchain adoption in the pharmaceutical industry using a fuzzy scale ranging from 0 to 1. In this scale, 0 signifies no relationship, while 1 signifies a strong relationship among the variables. To represent the directional relationship between two challenges (i, j), four symbols are used:

- V is used if challenge "i" influences or reaches challenge "j";
- A is used if challenge "j" reaches challenge "i";
- X is used if challenge "i" and challenge "j" influence each other and
- O is used if both challenges are unrelated (Palaniappan, Vinodh and Ranganathan, 2020).

Taking into consideration the connections within the given context, the development of the SSIM has been undertaken for 21 challenges and is given in Table 5.

Table 5. Structural self-interaction matrix.

Challenge code	Ch_{21}	Ch_{20}	Ch_{19}	Ch_{18}	Ch_{17}	Ch_{16}	Ch_{15}	Ch_{14}	Ch_{13}	Ch_{12}	Ch_{11}	Ch_{10}	Ch_9	Ch_8	Ch_7	Ch_6	Ch_5	Ch_4	Ch_3	Ch_2	Ch_1
Ch_1	V	O	V	O	V	V	V	V	V	A	V	V	O	A	V	O	V	V	V	V	X
Ch_2	A	V	V	V	V	V	V	V	A	V	O	O	X	V	V	A	V	V	A	X	
Ch_3	X	V	V	V	V	V	X	V	V	V	V	X	A	O	O	O	V	V	X		
Ch_4	A	A	A	X	V	V	V	X	A	A	O	V	A	A	O	A	A	X			
Ch_5	O	O	O	O	O	O	A	O	O	V	V	O	A	O	X	O	X				
Ch_6	O	O	O	V	O	O	O	V	O	O	O	V	O	O	O	X					
Ch_7	O	O	O	V	O	O	O	V	V	V	V	V	O	O	X						
Ch_8	A	O	A	V	O	O	V	V	X	V	V	V	O	X							
Ch_9	V	V	V	V	V	V	V	X	V	V	V	X	X								
Ch_{10}	V	O	V	V	X	O	X	V	X	O	O	X									
Ch_{11}	O	O	V	V	V	V	V	V	A	V	X										

Ch_{12}	O	A	V	X	V	V	V	V	A	X
Ch_{13}	V	V	V	X	V	V	X	V	X	
Ch_{14}	O	A	A	V	V	V	V	X		
Ch_{15}	V	V	V	X	X	V	X			
Ch_{16}	V	A	V	V	V	X				
Ch_{17}	X	A	V	X	X					
Ch_{18}	A	A	X	X						
Ch_{19}	A	A	X							
Ch_{20}	A	X								
Ch_{21}	X									

4.3.2. Creation of reachability matrix

After creating the SSIM, a reachability matrix is developed which is a representation of the accessibility of elements along a specific path [126]. The initial reachability matrix, is made by altering each entry of the SSIM into 1s and 0s. Following rules are obeyed for incorporation of binary entries:

- for (i, j) entry, if it is A in SSIM, then corresponding (i, j) entry in reachability matrix becomes "1" and (j, i) becomes "0";
- for (i, j) entry, if it is B in SSIM, then corresponding (i, j) entry in reachability matrix becomes "0" and (j, i) becomes "1";
- for (i, j) entry, if it is C in SSIM, then corresponding (i, j) entry in reachability matrix becomes "1" and (j, i) becomes "1" and
- for (i, j) entry, if it is D in SSIM, then corresponding (i, j) entry in reachability matrix becomes "0" and (j, i) becomes "0" [127].

The initial reachability matrix is then checked for transitivity which refers to a relationship involving three variables, wherein if a connection is identified between the first and second variables, as well as between the second and third variables, it logically implies the existence of a relationship between the first and third variables. By incorporating 1* in the initial reachability matrix to address any potential judgmental gaps that may arise following the collection experts´ opinions, transitivity is pointed, and the final reachability matrix is developed, represented in Table 6.

Table 6. Final reachability matrix.

Challenge code	**Ch_1**	**Ch_2**	**Ch_3**	**Ch_4**	**Ch_5**	**Ch_6**	**Ch_7**	**Ch_8**	**Ch_9**	**Ch_{10}**	**Ch_{11}**	**Ch_{12}**	**Ch_{13}**	**Ch_{14}**	**Ch_{15}**	**Ch_{16}**	**Ch_{17}**	**Ch_{18}**	**Ch_{19}**	**Ch_{20}**	**Ch_{21}**
Ch_1	1	1	1	1	1	1*	1	0	0	1	1	0	1	1	1	1	1	1*	1	1*	1
Ch_2	0	1	0	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	1	0
Ch_3	0	1	1	1	1	0	1*	1*	0	1	1	1	1	1	1	1	1	1	1	1	1
Ch_4	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	1	1	0	0	0
Ch_5	0	0	1	1	1	0	1	1*	0	1*	0	0	0	1*	0	1*	1*	1*	0	0	0
Ch_6	0	1	0	1	1*	1	1*	1*	1*	1	1*	1*	1*	1	1*	1*	1*	1	1*	1*	1*
Ch_7	0	0	0	1*	1	0	1	1*	1*	1	1	1	1	1	1*	1*	1*	1	1*	1*	1*
Ch_8	1	0	1*	1	1*	0	1*	1	1*	1	1	1	1	1	1	1*	1*	1	0	1*	0
Ch_9	1*	1	1	1	1	0	1*	1*	1	1	1	1	1	1	1	1	1	1	1	1	1
Ch_{10}	0	1*	1	0	1*	0	0	0	1	1	1*	1*	1	1	1	1*	1	1	1	1*	1
Ch_{11}	0	1	0	0	0	0	0	0	0	0	1	1	1*	1	1	1	1	1	1	1*	1*
Ch_{12}	1	0	0	1	0	0	0	0	0	1*	0	1	0	1	1	1	1	1	1	0	1*
Ch_{13}	0	1	0	1	1*	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ch_{14}	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	1*
Ch_{15}	0	0	1	0	1	0	0	0	0	1	0	0	1	0	1	1	1	1	1	1	1
Ch_{16}	0	0	0	0	0	0	0	1*	0	1*	0	0	0	0	0	1	1	1	1	0	1
Ch_{17}	0	0	0	0	0	0	0	1*	0	1	0	0	0	0	1	0	1	1	1	0	1
Ch_{18}	0	0	0	1	1*	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	0

Ch_{19}	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	0	0
Ch_{20}	1*	0	0	1	0	0	0	1*	0	1*	1*	1	0	1	1	1	1	1	1	1	0
Ch_{21}	0	1	1	1	0	0	1*	1	0	0	1*	1*	0	1*	0	0	1	1	1	1	1

4.3.3. Partition of the final reachability matrix into different levels

The final reachability matrix derived in section 4.3.2 was segmented into distinct levels. It facilitated the determination of the reachability and antecedent sets for each barrier according to [128]. The reachability set for the finalized challenges encompasses the challenges themselves and other enablers they may contribute to achieving. In the row corresponding to a specific considered factor, each column containing a 1 is included in the reachability set, representing the factor associated with that column. Conversely, the antecedent set comprises the challenges and other challenges that may give rise to them. The intersection of these sets was also calculated for all challenges. In the column corresponding to the considered factor, the antecedent set includes the factors represented by rows containing a value of 1. If the reachability set and the intersection set for a given barrier are identical, it is categorized as Level I and occupies the lowest position in the ISM hierarchy. This process marks the completion of iteration 1. Subsequently, the barriers identified in Level I are discarded, and the procedure continues with the remaining barriers in iteration 2. This iterative approach persists until the level of each barrier is determined [129]. The compiled iterations of challenges are outlined in Table 7.

Table 7. Levels of challenges.

Ch (Ch_i)	Reachability set	Antecedent set	Intersection	Level
Ch_1	1, 2, 3, 4, 5, 7, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21	1, 8, 9, 12, 18, 20	1, 18, 20	V
Ch_2	2, 4, 5, 7, 8, 9, 12, 14, 15, 16, 17, 18, 19, 20	1, 2, 3, 6, 9, 10, 13, 21	2, 9	IV
Ch_3	2, 3, 4, 5, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	1, 3, 6, 8, 9, 10, 15, 21	3, 8, 10, 15, 21	V
Ch_4	4, 10, 14, 15, 16, 17, 18	1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13, 14, 18, 19, 20, 21	4, 14, 18	III
Ch_5	4, 5, 7, 8, 10, 12, 13, 14, 16, 17, 18	1, 2, 3, 5, 6, 7, 8, 9, 10, 13, 14, 15, 16, 17, 18	5, 7, 8, 10, 13, 14, 16, 17, 18	II
Ch_6	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	6, 11, 12, 13, 15, 16, 17, 19, 20 ,21	6, 11, 12, 13, 15, 16, 17, 19, 20, 21	V
Ch_7	4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	1, 2, 3, 5, 6, 7, 8, 9, 15, 16, 17, 19, 20, 21	5, 7, 8, 9, 15, 16, 17, 19, 20, 21	IV
Ch_8	1, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20	2, 3, 5, 6, 7, 8, 9, 13, 16, 17, 19, 20, 21	3, 5, 7, 8, 9, 13, 16, 17, 20	IV
Ch_9	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	2, 6, 7, 8, 9, 10, 14	2, 7, 8, 9, 10, 14	IV
Ch_{10}	2, 3, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 20	3, 5, 9, 10, 11, 12, 13, 15, 16, 17, 20	V
Ch_{11}	6, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21	1, 3, 6, 7, 8, 9, 10, 11, 13, 19, 20, 21	6, 10, 11, 20, 21	III
Ch_{12}	1, 4, 6, 10, 12, 14, 15, 16, 17, 18, 21	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 18, 19, 20, 21	6, 10, 12, 18, 21	IV
Ch_{13}	2, 4, 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	1, 3, 5, 6, 7, 8, 9, 10, 13, 15, 18	5, 6, 8, 10, 13, 15, 18	V
Ch_{14}	4, 5, 9, 14, 15, 16, 17, 18, 21	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 19, 20, 21	4, 5, 9, 14, 21	III
Ch_{15}	3, 5, 6, 7, 10, 13, 15, 16, 17, 18, 19, 20, 21	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 20	3, 5, 6, 7, 10, 13, 15, 17, 18	III
Ch_{16}	5, 6, 7, 8, 10, 16, 17, 18, 19, 21	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 20	5, 6, 7, 8, 10, 16	II
Ch_{17}	5, 6, 7, 8, 10, 15, 17, 18, 19, 21	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	5, 6, 7, 8, 10, 15, 17, 18, 19, 21	I

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Ch_{18}	1, 4, 5, 12, 13, 15, 17, 18, 19	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	1, 4, 5, 12, 13, 15, 17, 18, 19	I
Ch_{19}	4, 6, 7, 8, 11, 12, 14, 17, 18 19	1, 2, 3, 6, 7, 9, 10, 13, 15, 16, 17, 18, 19, 20, 21	6, 7, 18, 19	IV
Ch_{20}	1, 4, 6, 7, 8, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20	1, 2, 3, 6, 7, 8, 9, 10, 11, 13, 15, 20, 21	1, 6, 7, 8, 10, 11, 20	III
Ch_{21}	2, 3, 4, 6, 7, 8, 11, 12, 14, 17, 18, 19, 20, 21	1, 3, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 21	3, 6, 7, 11, 12, 14, 17, 21	V

4.3.4. Development of fuzzy conical matrix

FISM represents an advancement over traditional ISM methodology. In FISM, an additional input, the possibility of interaction, is introduced on a 0-1 scale, excluding both 0 and 1, so, the traditional binary representation of relationships as 0 and 1 is replaced with quantifiable values on a fuzzy scale, providing a more nuanced data representation [130]. Unlike ISM, FISM incorporates a fuzzy scale. The fuzzy scale utilized in this study is detailed in Table 8 [131].

Table 8. Possibility of numerical value of the reachability.

Possibility of reachbility	**No.**	**Very low**	**Low**	**Medium**	**High**	**Very high**
Value	0	0.1	0.3	0.5	0.7	0.9

The final reachability matrix is then transformed based on this chosen fuzzy scale, resulting in a fuzzy final reachability matrix. This fuzzy reachability matrix is subsequently utilized to determine the dependence and driving power of the variables, detailed in Table 9. To streamline the analysis, a fuzzy conical matrix is constructed by consolidating factors at the same level across different rows and columns of the fuzzy final reachability matrix, as illustrated in Table 10. The drive power of a factor is computed by summing the number of ones in its corresponding rows, while the dependence power is calculated by summing the number of ones in its columns. Following this, ranks for dependence power and drive power are assigned, with top ranks granted to factors possessing the maximum number of ones in the rows and columns, respectively.

Table 9. Fuzzy final reachability matrix reachability.

Challenge code	**Ch_1**	**Ch_2**	**Ch_3**	**Ch_4**	**Ch_5**	**Ch_6**	**Ch_7**	**Ch_8**	**Ch_9**	**Ch_{10}**	**Ch_{11}**	**Ch_{12}**	**Ch_{13}**	**Ch_{14}**	**Ch_{15}**	**Ch_{16}**	**Ch_{17}**	**Ch_{18}**	**Ch_{19}**	**Ch_{20}**	**Ch_{21}**
Ch_1	1	1	1	1	1	0.1	1	0	0	1	1	0	1	1	1	1	1	0.3	1	0.1	1
Ch_2	0	1	0	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	1	0
Ch_3	0	1	1	1	1	0	0.5	0.5	0	1	1	1	1	1	1	1	1	1	1	1	1
Ch_4	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	1	1	0	0	0
Ch_5	0	0	1	1	1	0	1	0.1	0	0.5	0	0	0	0.3	0	0.1	0.3	0.3	0	0	0
Ch_6	0	1	0	1	0.1	1	0.1	0.1	0.1	1	0.1	0.3	0.5	1	0.1	0.1	0.3	1	0.1	0.1	0.3
Ch_7	0	0	0	0.3	1	0	1	0.3	0.1	1	1	1	1	1	0.5	0.1	0.5	1	0.1	0.1	0.3
Ch_8	1	0	0.5	1	0.3	0	0.1	1	0.1	1	1	1	1	1	1	0.1	0.5	1	0	0.1	0
Ch_9	0.3	1	1	1	1	0	0.1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1
Ch_{10}	0	0.3	1	0	0.5	0	0	0	1	1	0.5	0.3	1	1	1	0.3	1	1	1	0.1	1
Ch_{11}	0	1	0	0	0	0	0	0	0	0	1	1	0.3	1	1	1	1	1	1	0.1	0.3
Ch_{12}	1	0	0	1	0	0	0	0	0	0.1	0	1	0	1	1	1	1	1	1	0	0.3
Ch_{13}	0	1	0	1	0.5	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ch_{14}	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0.5
Ch_{15}	0	0	1	0	1	0	0	0	0	1	0	0	1	0	1	1	1	1	1	1	1
Ch_{16}	0	0	0	0	0	0	0	0.1	0	0.3	0	0	0	0	0	1	1	1	1	0	1
Ch_{17}	0	0	0	0	0	0	0	0.7	0	1	0	0	0	0	1	0	1	1	1	0	1
Ch_{18}	0	0	0	1	0.5	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	0
Ch_{19}	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	0	0
Ch_{20}	0.1	0	0	1	0	0	0	0.1	0	0.1	0.1	1	0	1	1	1	1	1	1	1	0
Ch_{21}	0	1	1	1	0	0	0.3	1	0	0	0.5	0.3	0	0.5	0	0	1	1	1	1	1

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Table 10. Fuzzy conical matrix.

Challenge code	Ch19	Ch16	Ch4	Ch5	Ch17	Ch14	Ch18	Ch6	Ch20	Ch12	Ch11	Ch7	Ch21	Ch15	Ch8	Ch10	Ch2	Ch1	Ch13	Ch3	Ch9	Driving power
Ch19	1	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5
Ch16	1	1	0	0	1	0	1	0	0	0	0	0	1	0	0.1	0.3	0	0	0	0	0	5.4
Ch4	1	1	1	0	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	8
Ch5	0	0.1	1	1	0.3	0.3	0.3	0	0	0	0	1	0	0	0.1	0.5	0	0	0	1	0	5.6
Ch17	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0.7	1	0	0	0	0	0	6.7
Ch14	0.1	1	1	0	1	1	1	0	0	0	0	0	0.5	1	0	0	0	0	0	0	1	7.5
Ch18	0.1	0	1	0.5	1	0	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	7.5
Ch6	0	0.1	1	0.1	0.3	1	1	1	0.1	0.3	0.1	0.1	0.3	0.1	0.1	1	1	0	0.5	0	0.1	8.3
Ch20	1	1	1	0	1	1	1	0	1	1	0.1	0	0	0	0.3	0.1	0	0.1	0	0	0	8.6
Ch12	1	1	1	0	1	1	1	0	0	1	0	0	0.3	1	0	0.1	0	1	0	0	0	9.4
Ch11	1	1	0	0	1	1	1	0	0.1	1	1	0	0.3	1	0	0	1	0	0.3	0	0	9.7
Ch7	1	0.1	0.3	1	0.5	1	1	0	0.1	1	1	1	0.3	0.5	0.3	1	0	0	1	0	0.1	10.3
Ch21	1	0	1	0	1	0.5	1	0	1	0.3	0.5	0.3	1	0	1	0	1	0	0	1	0	10.7
Ch15	0	1	0	1	1	0	1	0	1	0	0	0	1	1	0	1	0	0	1	1	0	10
Ch8	1	0.1	1	0.3	0.5	1	1	0	0.1	1	1	0.1	0	1	1	1	0	1	1	0.5	0.1	11.7
Ch10	1	0.3	0	0.5	1	1	1	0	0.1	0.3	0.5	0	1	1	0	1	0.3	0	1	1	1	12
Ch2	1	1	1	1	1	1	1	0	1	1	0	1	0	1	1	0	1	0	0	0	1	14
Ch1	1	1	1	1	1	1	0.3	0.1	0.1	0	1	1	1	1	0	1	1	1	1	1	0	15.5
Ch13	1	1	1	0.5	1	1	1	0	1	1	1	0	1	1	1	1	1	0	1	0	0	15.5
Ch3	1	1	1	1	1	1	1	0	1	1	1	0.5	1	1	0.5	1	1	0	1	1	0	17
Ch9	1	1	1	1	1	1	1	0	1	1	1	0.1	1	1	0.5	1	1	0.3	1	1	1	17.9
Dependence power	15.2	12.6	15.3	8.9	17.6	15.8	19.6	1.1	7.6	10.9	8.2	5.1	10.7	14.6	7.6	12	8.3	3.4	9.8	7.5	4.3	215.2/215.2

4.3.5. Creation of FISM model fuzzy conical matrix

Considering the fuzzy conical matrix, a FISM model is developed based on the relationships given above in the fuzzy final reachability matrix. The structural model is derived from the final reachability matrix and the segmented levels. If there exists a relationship between challenges i and j, it is represented by an arrow pointing from i to j in a directed graph or diagraph. This diagraph illustrates all potential dependencies and transitivities among the challenges, generated from one level to another. The concept of transitivity in challenges is acknowledged, where if challenges i are related to j and challenges j are related to k, then challenges i would also be considered related to k [86]. Ultimately, the nodes of all elements are replaced with corresponding statements, and the digraph is transformed into an FISM model, as shown in Figure 3.

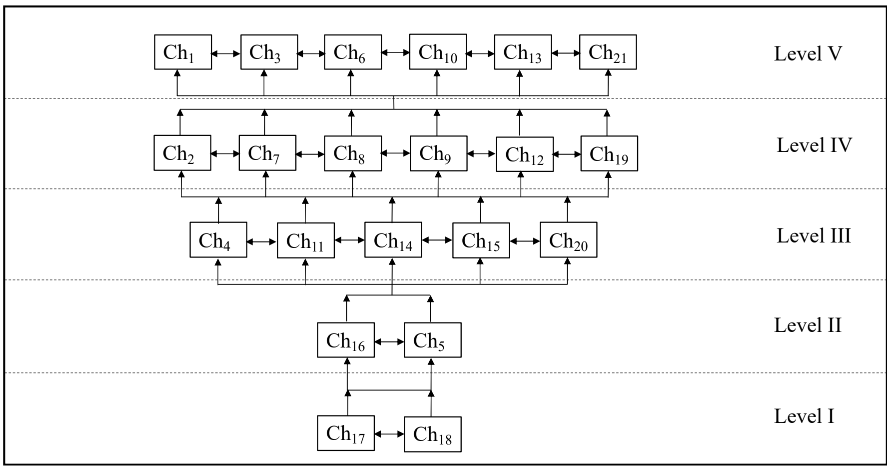

Figure 3. FISM model.

4.4. MICMAC analysis

The MICMAC analysis is conducted based on the principle of matrix multiplication, with the objective of assessing the driving and dependence force for each construct and subsequently categorizing the research variables accordingly [62]. The dependence and driving power of the factors are illustrated in Table 10. Subsequently, a diagram depicting the dependence and driving power is generated in Figure 4. Clusters of challenges affecting the blockchain adoption. There are three challenges with weak driving power and weak dependency, indicating that these are not related to the other barriers in the model. Seven challenges are included in the second cluster (weak driving power, strong dependency) thus, these challenges occupy elevated positions in the ISM-based model. Strong driving power and high dependency can be found by four challenges which means they play a crucial role in the interconnectedness and dynamics. Independent challenges have strong driving power as well as a strong dependency. The seven challenges occurring in the fourth cluster are strategically important, and changes in these factors can have significant implications for the overall behavior. By displaying the existing connections among the challenges related to the blockchain adoption in the pharmaceutical industry, RQ2 has been addressed.

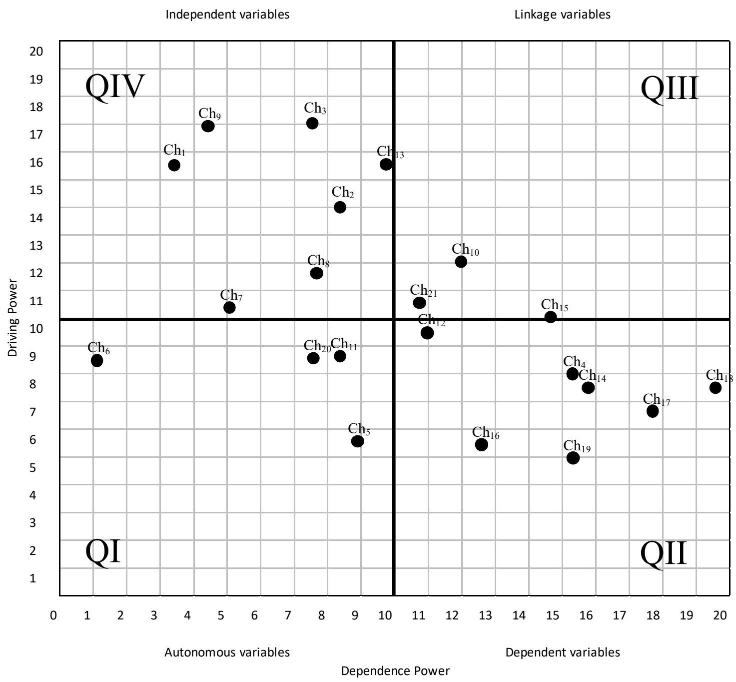

Figure 4. Clusters of challenges affecting the blockchain adoption.

5. Discussion and implications

This research aims to assess the significant factors influencing the adoption of blockchain in the pharmaceutical industry. The objective is to provide pharmaceutical management and policymakers with insights for more effective and efficient handling of these factors. Utilizing the FISM approach, a comprehensive model has been developed to thoroughly examine the interrelations among these factors.

5.1. Discussion

Although the implementation of blockchain technology shows great potential for fostering sustainable development in the pharmaceutical industry, and despite an increasing amount of research on the hurdles linked to its adoption, a thorough comprehension of the potential challenges in embracing blockchain is still in its infancy. Therefore, this study empirically analyzes the challenges affecting blockchain adoption in the pharmaceutical industry. This model assists in establishing a hierarchy of actions and activities that management can undertake to address the noteworthy impacts on blockchain adoption within the pharmaceutical industry. This information is crucial for decision-makers and policymakers to formulate effective strategies promoting blockchain adoption in the pharmaceutical sector.

The findings present five distinct levels of dimensions describing relationships among the selected barrier factors. The first level in the hierarchy encompasses Ch17 and Ch18. The second level includes Ch5, and Ch16. The third level involves Ch4, Ch11, Ch14, Ch15, and Ch20. The fourth level comprises Ch2, Ch7, Ch8, Ch9, Ch12, and Ch19. The fifth level highlights Ch1, Ch3, Ch6, Ch10, Ch13, and Ch21. Figure 3 illustrates that Ch_1, Ch_3, Ch_6, Ch_{10}, Ch_{13}, and Ch_{21} represent the most significant challenges to blockchain adoption in the pharmaceutical industry. Positioned at the bottom of the entire structural hierarchy, they form the foundation of the entire model. Some of these observations can be explained by the distinctive features of the current pharmaceutical industry whereas other are generic. The sector, known for its complex supply chains and stringent regulatory requirements, places a premium on secure data management. However, the implementation of blockchain solutions, which demands significant investments in technology infrastructure and maintenance, becomes a formidable financial challenge. Justifying these costs is further complicated by the industry's already substantial expenditures in research, development, and compliance. This financial challenge is closely linked to the need for strong leadership support in successful blockchain adoption. Without full management commitment, not only does justifying high costs become more difficult, but it also hampers resource allocation, decision-making processes, and the overall integration of blockchain into existing systems. Widespread unfamiliarity with blockchain technology and its potential applications is not only an issue fostering the lack of management support but rather poses a significant general challenge. Many stakeholders, ranging from industry professionals to regulators and the public, may not fully grasp the intricacies and advantages of blockchain. The imperative lies in conducting extensive educational initiatives to raise awareness and demystify blockchain, ensuring a more informed and receptive audience. Industry associations, regulatory bodies, and influential stakeholders can play a pivotal role in disseminating information. Implementing educational programs targeting professionals at all levels will contribute to a broader understanding of blockchain's potential and benefits. The scarcity of professionals with specialized blockchain skills exacerbates these challenges. The pharmaceutical industry struggles to find and retain talent proficient in cryptography, distributed ledger technology, and smart contract development. This shortage not only slows down the adoption process but also jeopardizes the effective utilization of blockchain within the industry. The emphasis on data accuracy and integrity in the pharmaceutical industry is intricately tied to the immutability of blockchain. While blockchain ensures data integrity, the challenge arises in situations requiring flexibility, such as regulatory changes or corrections to erroneous data, where the inability to alter information becomes a delicate consideration. Thus, the challenge of ensuring the immutability of blockchain data poses concerns about data integrity. These challenges collectively contribute to the lack of market acceptance. Achieving widespread acceptance necessitates collaboration and consensus among various stakeholders, including regulatory bodies, healthcare providers, and patients. The reluctance or skepticism of key players to embrace blockchain technologies introduces a significant barrier. Trust and acceptance, therefore, play pivotal roles in the successful integration of technological innovations within the pharmaceutical sector.

The results of the MICMAC-analysis illustrate the drive power dependence matrix, derived from the model, that also provides pharmaceutical professionals and managers valuable information for a comprehensive understanding of the relative importance, interdependencies, and relationships among these factors. The drive and dependence power diagram further provides insights into their importance and interdependencies. The matrix depicting drive and dependence power reveals the presence of three autonomous challenges, namely Ch_6, Ch_{20}, and Ch_5. This indicates that these challenges exert minimal influence on the system, possessing both weak driving and dependent power, indicating less importance within the system. The dependent cluster comprises seven variables: Ch_{16}, Ch_4, Ch_{19}, Ch_{14}, Ch_{17}, Ch_{12}, and Ch_{18}. Given their characteristics of weak drive power but strong dependence power, these factors demand heightened priority in management

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considerations. Furthermore, managers should consider the dependence of these factors on elements at other levels within the ISM framework. These findings align with the results of Xu, Chong, and Chi (2023), whose study on modeling blockchain adoption barriers identified among others "Reluctance to change business processes" and "Lack of collaboration and network establishment" as having the lowest driving values, both overall and within the cluster of dependent factors. Within the range of the linkage factors, Ch_{21}, Ch_{15}, Ch_{10}, and Ch_{13} are positioned. These factors exhibit both robust driving and substantial dependence power. Any minor intervention undertaken on these challenges is poised to yield a notable impact on other elements, and they also exhibit a feedback effect on themselves. These factors play a crucial role in fostering a positive environment conducive to blockchain adoption in the pharmaceutical industry. Final, Ch_1, Ch_9, Ch_3, Ch_2, Ch_8, Ch_7, and Ch_{11} stand as independent factors, boasting formidable drive power but exhibiting limited dependence power. These are pivotal elements acknowledged as the foundational causes influencing all other factors. This result coincides with Yadav et al. (2020), Sahebi et al. (2020), and Sharma et al. (2021) whose conclusion emphasized that the principal barrier to blockchain adoption is the "Lack of government regulations and support".

5.2. Academic implications

The SLR highlights numerous studies addressing challenges associated with blockchain adoption, encompassing perspectives tailored to specific industries and those of a more universal nature. However, only a limited number of studies examine the interrelationships among these challenges. No prior study has assessed of the challenges in blockchain adoption with the specific goal of improving the sustainability performance of the pharmaceutical industry. This study pioneers a comprehensive examination of challenges in blockchain adoption within the pharmaceutical industry, contributing to a nuanced understanding of associated challenges and their interconnections for further exploration. Acknowledging the impracticality of addressing all challenges simultaneously, the research initially identified key factors through a SLR and expert feedback. Subsequently, utilized an integrated decision framework, incorporating FISM- and MICMAC-analysis, to discern the interdependencies as well as driving and dependence powers of challenges associated with adopting blockchain in the pharmaceutical industry. Serving as an intriguing first step in research progression, this study encourages scholars to focus on overcoming challenges to blockchain adoption in the pharmaceutical industry in future studies. Importantly, the research establishes a foundational framework for subsequent empirical analyses aimed at exploring determinants of blockchain technology adoption in the pharmaceutical sector.

5.3. Managerial implications

Vigilant monitoring of crucial variables is essential to foster a conducive environment in the pharmaceutical industry for effective blockchain adoption, enhancing sustainability performance. The model elucidates the intricate interconnections and mutual influences among diverse factors impacting blockchain adoption in the pharmaceutical industry. Evolving challenges in the industry, driven by shifts in market dynamics and patient demands, underscore the growing need for enhanced supply chain visibility and more effective recall processes [134,135]. Considering these challenges, this research scrutinizes pivotal factors influencing blockchain adoption in the pharmaceutical industry, offering a revamped model to guide management in navigating these factors successfully.

Functioning as a disruptive and innovative technology, blockchain has the potential to enhance trust in relationships, ensure secure payments, streamline processes, minimize transaction costs, and improve traceability. Nevertheless, numerous technical, environmental, and organizational challenges persist, as emphasized by the findings of this study. The results underscore that Ch_1, Ch_3, Ch_6, Ch_{10}, Ch_{13}, and Ch_{21} stand out as the most critical barriers, suggesting that the pharmaceutical industry is presently inadequately equipped for the adoption of blockchain. It is imperative for top-level management and policymakers in the sector to take decisive and effective actions, demonstrating their commitment to minimizing these barriers. These barriers exhibit significant

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driving power, acting as fundamental causes for the emergence of other obstacles. Therefore, management and policymakers should progressively diminish barriers with substantial driving power to attain the desired objectives in the pharmaceutical sector.

The "High costs of blockchain investments" challenge in pharmaceuticals stems from initial implementation expenses, regulatory compliance, and the need for employee training. To address this, collaborative industry efforts, government incentives, and technological solutions like Blockchain as a Service can help offset costs. A phased implementation approach allows companies to prioritize key areas and demonstrate blockchain's value gradually, managing expenses more effectively. Overcoming the financial challenge in blockchain adoption requires securing strong leadership support. Without full management commitment, justifying costs becomes difficult, hindering resource allocation and integration. To address this, organizations should educate leaders on blockchain benefits, demonstrate clear ROI, initiate small-scale pilots, align initiatives with organizational goals, create phased roadmaps, foster cross-functional collaboration, maintain transparent communication, and develop robust risk management strategies. Building confidence in the technology's potential and showcasing incremental successes are key to gaining the necessary commitment for successful blockchain integration. Ensuring the immutability of blockchain data poses concerns about data integrity. Solutions involve employing advanced consensus mechanisms, periodic audits, and adopting hybrid models that balance transparency with necessary flexibility. Collaboration within the industry can establish standards for immutable data while allowing for occasional adjustments. Overcoming skepticism and fostering trust in blockchain technology requires strategic communication, education initiatives, industry partnerships, and advocacy to promote its benefits and showcase successful use cases. Fostering a culture of experimentation and showcasing tangible outcomes contributes to wider acceptance. It requires strategic communication and education initiatives. Industry partnerships and advocacy can promote the benefits of blockchain, demonstrating successful use cases. Fostering a culture of experimentation and showcasing tangible outcomes will contribute to wider acceptance. The shortage of professionals well-versed in blockchain technology poses a significant challenge. Implementing blockchain requires specialized knowledge in areas like cryptography, distributed ledger technology, and smart contracts. Addressing the shortage of technology expertise involves investing in training programs, collaborations with educational institutions, and encouraging a cross-disciplinary approach. Companies can also leverage external expertise through partnerships and consultancy to bridge the skills gap during the initial phases of blockchain implementation. Addressing widespread unfamiliarity with blockchain and its advantages as well as potential requires a comprehensive approach. Initiatives such as educational programs, collaboration with industry associations, engagement with regulatory bodies, and public awareness campaigns, along with accessible online resources and practical applications, aim to create an informed and supportive environment for blockchain adoption.

6. Conclusion and limitations

6.1. Conclusion

The benefits of blockchain technology and its applicability across various industries have prompted companies to integrate blockchain into their operations. Existing literature on the challenges associated with blockchain adoption has examined both industry-specific and general perspectives. However, there is a gap in the literature concerning the analysis of challenges specific to blockchain adoption in the pharmaceutical industry. This study conducted a preliminary investigation into the significant challenges hindering the adoption of blockchain technology in the pharmaceutical industry for the purpose of enhancing sustainability performance. By conducting a SLR and obtaining feedback from 18 experts, a total of 21 key barriers were identified and analyzed. The FISM analysis was employed to construct a hierarchical model and determine relationships among the factors. To assess the driving and dependence power of the barriers, a MICMAC analysis grouped factors into four clusters. The research findings reveal that the 21 factors are divided into

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five levels, with Ch_1, Ch_3, Ch_6, Ch_{10}, Ch_{13}, and Ch_{21} identified as the primary challenges to blockchain adoption in the pharmaceutical industry. This research serves as a valuable preliminary study, establishing the groundwork for future research. The integrated FISM-MICMAC approach offers academicians and industrialists a comprehensive overview of the challenges associated with blockchain adoption in the pharmaceutical industry. The findings offer essential guidance for practitioners in the pharmaceutical industry and government policymakers, particularly in the selection of potential solutions to address the identified challenges to blockchain adoption ensuring long-term success and competitiveness in the market. Consequently, this proposed FISM model guides business managers in devising operational strategies to address challenges related to blockchain adoption. Before the actual adoption of blockchain into their firms, management gains a clear understanding of the hierarchy of factors. Subsequently, organizations can frame competitive strategies based on the driving and dependence power of various factors.

6.2. Limitations

This research is subject to certain limitations. A notable limitation in the current study lies in establishing interdependencies among the critical challenges to blockchain adoption based on subjective judgments from the expert group, introducing the potential for personal bias in the results. To address this, future studies should aim to engage multiple stakeholder perspectives, evaluating barriers and comparing their similarities and differences. This approach will facilitate a more objective decision-making process for policymakers and policy planners. The online survey method was employed, and it comes with the limitation that detailed information about the sample is not available and there is no certainty that participants have accurately provided demographic or characteristic information (Query and Wright, 2003; Wright, 2005). Additionally, a conceptual model involving different factors influencing lean implementation in hospitals has been constructed, incorporating insights from a literature review, inputs gathered through discussions with experts in the relevant field, and findings from the survey. It's important to acknowledge that the model may deviate from real-world scenarios, and the relationships between various factors might differ from those depicted in the derived model. This discrepancy arises because the FISM methodology employed does not quantify the impact of each variable. Moreover, further empirical studies are necessary to gain deeper insights into critical challenges. Structural equation modeling could be employed to validate cause–effect relationships, game theory might be utilized to assign objective weights to criteria for more reasonable results, and adaptive neuro-fuzzy inference systems could be applied to quantitatively prioritize identified challenges. Also, comprehensive, and longitudinal studies are warranted to explore whether the prominence of identified factors and their relationships varies across countries and cultures, and to assess how the evolution of these challenges impacts the advancement of new technologies in the pharmaceutical industry.

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