**Appendices**

**Appendix A**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Paper** | **Sector** | | | **Type of study** | | **Limitations** |
| **Healthcare** | | **Other** | **Review** | **Empirical** |
| **Pharmaceutical** | **General** |  |
| Schmidt et al. (2024) |  |  | Circular economy | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Singh et al. (2024) |  |  | Waste management | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hawashin et al. (2024) |  |  | Robotics | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Farah et al. (2024) |  |  | Maritime | X |  | - Not specific on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hoque et al. (2024) |  |  | Financial service | X | X | - Not specific on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Surucu-Balci et al. (2024) |  |  | Maritime | X |  | - Not specific on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Kannan et al. (2024) |  |  | Circular economy | X | X | - Not specific on pharmaceutical/medical sector  - No countermeasures proposed |
| Gupta et al. (2024) |  |  | Logistics | X | X | - Not specific on pharmaceutical/medical sector  - No countermeasures proposed |
| Akram et al. (2024) |  |  | Food | X | X | - Not specific on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Yousefi and Tosarkani (2024) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Kassen (2024) |  |  | General |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Quayson et al. (2024) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Terrizzi et al. (2024) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| BelMannoubi et al. (2023) |  |  | Intelligent transport systems | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Singh et al. (2023b) |  |  | Construction | X | X | - Not on pharmaceutical/medical sector  - No challenge prioritization |
| Jiang et al. (2023) |  |  | Waste management | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Singh et al. (2023a) |  |  | Construction | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Ullah et al. (2023) |  |  | Smart cities | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Chen et al. (2023) |  | X |  |  | X | - Not specific on pharmaceutical sector  - No challenge prioritization  - No countermeasures proposed |
| Vafadarnikjoo et al. (2023) |  |  | Manufacturing | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Das et al. (2023) |  |  | Intelligent transport systems | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Su et al. (2023) |  |  | Manufacturing | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Kumar Singh et al. (2023) |  |  | Construction | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| J et al. (2023) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Komulainen and Nätti (2023) |  |  | Financial service |  | X | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Bak et al. (2023) |  | X |  |  | X | - Not specific on pharmaceutical sector  - No challenge prioritization  - No countermeasures proposed |
| Liu et al. (2023) |  |  | Maritime | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Li et al. (2023) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Qahtan et al. (2023) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Yadav et al. (2023) |  | X |  | X | X | - Focus only on vaccine supply chain  - No countermeasures proposed |
| Arbabi et al. (2023) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Ghadge et al. (2023) | X |  |  | X |  | - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Govindan et al. (2023) |  | X |  | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Vern et al. (2023) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Mohammed et al. (2023a) |  |  | Food |  | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Mohammed et al. (2023a) |  |  | Food | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Yadlapalli et al. (2022) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Govindan (2022) |  |  | Circular economy | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Erol et al. (2022) |  |  | Tourism | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Bamakan et al. (2022) |  |  | Waste management | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Yu et al. (2022) |  |  | Electronics | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Wang et al. (2022) |  |  | Energy | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Okorie et al. (2022) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Srivastava and Dashora (2022) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Balci and Surucu-Balci (2021) |  |  | Maritime | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Srinivas Aditya et al. (2021) |  |  | Robotics | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Toufaily et al. (2021) |  |  | General |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Hosseini Bamakan et al. (2021) | X |  |  | X |  | - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Mathivathanan et al. (2021) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Ghode et al. (2021) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Kouhizadeh et al. (2021) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Namasudra et al. (2021) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Thakker et al. (2021) |  |  | Diamond | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Nurgazina et al. (2021) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Dutta et al. (2020) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Ali et al. (2020) |  |  | Financial service | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Upadhyay (2020) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Durneva et al. (2020) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Feng et al. (2020) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Wamba and Queiroz (2020) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Y. Chang et al. (2020) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Lohmer and Lasch (2020) |  |  | Manufacturing | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| V. Chang et al. (2020) |  |  | Financial service |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Yadav et al. (2020) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Farooque et al. (2020) |  |  | Lifecycle assessment |  | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Rejeb et al. (2020) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hughes et al. (2019) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Kumar et al. (2020) |  |  | Supply Chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Biswas and Gupta (2019) |  |  | General | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Zhao et al. (2019) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Namasudra et al. (2021) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Saberi et al. (2019) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Queiroz and Fosso Wamba (2019) |  |  | Supply chain |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Bathula et al. (2024) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Mackey et al. (2019) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Kamel Boulos et al. (2018) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| McGhin et al. (2019) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Saeed et al. (2022) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hasselgren et al. (2020) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Tandon et al. (2020) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Pesqueira et al. (2024) | X |  |  | X |  | - On a specific pharmaceutical application  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hock et al. (2020) | X |  |  | X |  | - On a specific pharmaceutical application  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Uddin et al. (2021) | X |  |  | X |  | - On a specific pharmaceutical application  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Dash et al. (2021) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |

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**Appendix B**

Questionnaire Delphi Study Countermeasures

\* Mandatory

Research and Round Description

This study will map the current **challenges** and possible **countermeasures** of adopting a BlockChain in the pharmaceutical industry.

These will be provided to all participants in the Delphi study and will be used to define future research directions for academics.

In this round experts are required to suggest possible **countermeasures** to the proposed challenges. Individual participant ratings will not be shared with others to ensure anonymity

Anagraphical Informations

1. Name: \*
2. Surname: \*
3. Email: \*

Challenge 1

4. Indicate eventual countermeasures for the challenge **“High investment costs”** as described below: \*

"Implementing blockchain requires significant investment costs, with companies needing to develop software and invest in expensive hardware"

Challenge 2

5. Indicate eventual countermeasures for the challenge **“Lack of regulations”** as described below: \*

"Regulations about data security and privacy laws need to be put in place by governmental bodies to support the widespread adoption of blockchain. These are however currently missing"

Challenge 3

6. Indicate eventual countermeasures for the challenge **“Lack of managerial support”** as described below: \*

"Support from senior management is crucial for the successful implementation and adoption of blockchain"

Challenge 4

7. Indicate eventual countermeasures for the challenge **“IT security”** as described below: \*

"The implementation and use of blockchain is subject to IT security issues, such as data vulnerabilities, hacking risks, etc."

Challenge 5

8. Indicate eventual countermeasures for the challenge **“Data immutability”** as described below: \*

"Once data are recorded in a blockchain, they cannot be easily altered or deleted: while this is a key feature of blockchain, it can pose some challenges if errors are made or if there is a need to update information"

Challenge 6

9. Indicate eventual countermeasures for the challenge **“Lack of interoperability”** as described below: \*

"Interoperability is the capability of different blockchain networks or systems to communicate and share data seamlessly. If this is missing, efficient data exchange is hence hindered"

Challenge 7

10. Indicate eventual countermeasures for the challenge **“Lack of standardization”** as described below: \*

"Various blockchain applications are following different blockchain standards. The lack of standardization about transaction structures, validation, and security complicates the adoption of blockchain since companies lack clear rules and standards to follow"

Challenge 8

11. Indicate eventual countermeasures for the challenge **“High need of resources”** as described below: \*

"A correct implementation and adoption of blockchain requires significant requirements in terms of time and resources"

Challenge 9

12. Indicate eventual countermeasures for the challenge **“Lack of governmental support”** as described below: \*

"Governmental support in terms of economic incentives and regulations is needed; this is however currently lacking, hence hindering blockchain adoption"

Challenge 10

13. Indicate eventual countermeasures for the challenge **“Lack of customers’ acceptance”** as described below: \*

"Customers’ acceptance is crucial for convincing managers to adopt blockchain. If this is missing, this acts as a deterrent for blockchain adoption"

Challenge 11

14. Indicate eventual countermeasures for the challenge **“Lack of scalability”** as described below: \*

"Blockchains are characterized by restricted block size, which cannot be increased. This reduces transactions speed, which limits blockchain adoption by affecting the ability to handle growing transactions"

Challenge 12

15. Indicate eventual countermeasures for the challenge **“Need for maintenance”** as described below: \*

"Blockchain requires regular maintenance, otherwise it experiences slower transaction speeds, reduced efficiency, and higher data security issues"

Challenge 13

16. Indicate eventual countermeasures for the challenge **“Lack of skilled personnel”** as described below: \*

"There is limited amount of personnel skilled in blockchain, which is instead needed to fully exploit the benefits of blockchain"

Challenge 14

17. Indicate eventual countermeasures for the challenge **“Privacy concern”** as described below: \*

"Blockchain transactions are recorded on a public database accessible to anyone. This gives rise to privacy concerns"

Challenge 15

18. Indicate eventual countermeasures for the challenge **“Lack of collaboration”** as described below: \*

"A successful blockchain network requires the participation and commitment of all involved parties. It is however hard to convince all the involved parties and to ensure their cooperation, communication, and coordination"

Challenge 16

19. Indicate eventual countermeasures for the challenge **“Lack of knowledge on benefits”** as described below: \*

"Blockchain is new and in a developmental phase. Therefore, managers do not know what would be the benefit achievable and hence doubt about its adoption"

Challenge 17

20. Indicate eventual countermeasures for the challenge **“Workforce resistance”** as described below: \*

"Employees are reluctant to adopt blockchain and to change their processes to accommodate its implementation"

**Appendix C**

***Data immutability***

Data immutability, meaning that data *“cannot be changed or modified”*, is one of the main characteristics of blockchain technology (Mahjoub et al., 2022). This characteristic represents one of the most attracting characteristics of blockchain as it *“ensures reliability and authenticity of information”* (Kouhizadeh et al., 2021). However, despite its attracting feature, data immutability is accompanied also by an issue. Indeed, as reported by Kouhizadeh et al. (2021), *“an issue that arises with immutability is that previous data and errors within the records are permanent, as they will continue to live with the blockchain”*.

In conclusion, we can derive the following proposition:

***Proposition P1:*** Once data are recorded in a blockchain, they cannot be easily altered or deleted: while this is a key feature of blockchain, it can pose some challenges if errors are made or if there is a need to update information

***High investment costs***

As in any other sector (Abadi and Brunnermeier, 2018; Ruoti et al., 2020), also in the pharmaceutical sector the cost of implementing blockchain is high and it is considered a barrier (Radanović and Likić, 2018; Toufaily et al., 2021). As an example, Dhingra et al. (2024) stated that *“another noteworthy observation is that a high cost is associated with establishing and managing the blockchain network”*. Saberi et al. (2019) provide an important distinction, noting that these costs often stem not from the blockchain infrastructure itself (which has now become easily accessible in some cases (Webisoft, 2025)), but from the need to invest in complementary technologies. Specifically, they state that *“blockchain technology requires investing in new hardware and software for information collection, which is costly for organisations and network partners”*. Since blockchain is fundamentally a distributed database and cannot collect data autonomously, organizations must implement supporting technologies such as sensors, RFID, IoT devices, and dedicated data management systems to fully leverage its potential.

In conclusion, we can derive the following proposition:

***Proposition P2:*** Implementing blockchain requires significant investment costs, with companies needing to develop software and invest in expensive hardware

***High need of resources***

When adopting a new technology, one should not consider only the costs for purchasing software and hardware, i.e. the mere installation costs, but it should also consider the time and resources required to learn how to use such new technology. This is the case for all the new technologies (Hung and Chu, 2006; Khan and Turowski, 2016; Salomon and Martin, 2008), and blockchain is not exempt from it. Indeed, as stated by Balci and Surucu-Balci (2021), *“organisations need to train and upskill employees and invest some time and resources”*. Similarly, Dhingra et al. (2024) reported that training-associated costs concur to *“increase the associated cost”* and hence pose a risk to the blockchain adoption

In conclusion, we can derive the following proposition:

***Proposition P3:*** A correct implementation and adoption of blockchain requires significant requirements in terms of time and resources

***IT security***

Blockchain technology has been widely recognized for its potential to enhance data integrity and transparency across various sectors, including pharmaceuticals. However, its implementation is not without challenges, particularly concerning IT security. As Saberi et al. (2019) note, *“data security and privacy concerns are also challenges of using blockchain technology,”* while Hosseini Bamakan et al. (2021) highlight that *“the data faces potential privacy and security risks”*. Toufaily et al. (2021) further elaborate, stating that *“security, as a possibility of 51% attack, hard forks and system bugs for permissionless blockchains, and a risk of fraud, centralized control, risk of data tampering and lack of consensus mechanisms for permissioned blockchains is a challenge to the adoption of the technology”*. More in details, in the case of permissionless blockchains, the open nature of the network introduces several technical security vulnerabilities. For example, the Bitcoin network has historically faced risks from 51% attacks, where malicious actors controlling a majority of the network’s computing power could alter transaction history (Chen et al., 2023). The Basel Committee on Banking Supervision (2024) also warns that permissionless systems expose users to risks from malicious third-party validators, Sybil attacks, and smart contract exploits, due to the lack of identity verification among participants. In contrast, permissioned blockchains, while more commonly used in enterprise contexts such as pharmaceuticals, are not immune to cyber threats. Because participants are known and access is restricted, the main risks often come from within the network. According to Trend Micro (2023), insider threats – including malicious actions by authorized users – pose a significant security concern, as these actors may exploit their access to alter or leak sensitive data. In addition, NordLayer (2024) highlights that phishing attacks remain effective in these environments, with attackers targeting private keys or credentials of permissioned users to gain unauthorized access. Halborn (2024) further emphasizes that weak private key management in enterprise blockchains can lead to unauthorized transactions, while configuration errors in consensus protocols may expose systems to denial-of-service attacks or governance manipulation.

Hence, we can derive the following proposition:

***Proposition P4:*** The implementation and use of blockchain is subject to IT security issues, such as data vulnerabilities, hacking risks, etc.

***Lack of customers’ acceptance***

As stated by Chen et al. (2021), “customers’ and users’ acceptance also needs to be considered during blockchain implementation”. However, according to Kouhizadeh et al. (2021), *“the adoption of blockchain technology, although hyped for years, has not seen rapid acceptance”*. Similarly, Sander et al. (2018) stated that *“BCT is still in its early stages and needs more time to achieve full acceptance, application and potential”*. Such low customers’ acceptance, in turn, acts as a deterrent for blockchain adoption: as stated by Kouhizadeh et al. (2021) *“it is evident that risk and (low) customers’ acceptance are critical initial concerns for this emergent technology and its application to practice”* and according to Sander et al. (2018) there is “the need for a change in mentality” to ensure blockchain’s diffusion.

In conclusion, we can derive the following proposition:

***Proposition P5:*** Customers’ acceptance is crucial for convincing managers to adopt blockchain. If this is missing, this acts as a deterrent for blockchain adoption

***Lack of governmental support***

According to Hussien et al. (2019), the lack of governmental initiatives was among the most crucial challenges to hinder blockchain adoption. A similar result was reported in Kassab et al. (2021). Notably, among the governmental initiatives, they did not only consider economic initiatives such as incentives or other similar economic benefits to support the blockchain adoption, but also the introduction of regulations. Indeed, as stated by Upadhyay et al. (2021), *“government regulations are not yet completely supportive of blockchain technology”*. Similarly, Saberi et al. (2019) reported that the *“lack of appropriate governmental policy (…) is a hurdle for achieving advanced technological (i.e. blockchain) supporting mechanisms”*. In conclusion, as stated by Orji et al. (2020), *“government policy and support is an influential environmental factor of blockchain adoption”*.

Hence, we can derive the following proposition:

***Proposition P6:*** Governmental support in terms of economic incentives and regulations is needed; this is however currently lacking, hence hindering blockchain adoption

***Lack of interoperability***

As reported by Toufaily et al. (2021), *“a lack of interoperability between different blockchain frameworks, networks and platforms, as well as between blockchain networks and legacy systems, is a significant concern acknowledged in the literature”*. Indeed, *“each blockchain has its own distinctive characteristics, e.g., consensus mechanism, governance mechanism, different protocols, and coding languages, which restricts these blockchain from interacting with each other”* (Mahjoub et al., 2022). Therefore, to maximize the power of blockchain, *“agreements will need to be reached about data interoperability”* (Hileman and Rauchs, 2017). This is however currently missing, and *“interoperability is anticipated to be a challenge that will take time, skills and facilities to be resolved”* (Toufaily et al., 2021).

In conclusion, we can derive the following proposition:

***Proposition P7:*** Interoperability is the capability of different blockchain networks or systems to communicate and share data seamlessly. If this is missing, efficient data exchange is hence hindered.

***Lack of managerial support***

As stated by Toufaily et al. (2021), top management support *“is crucial for (any) technology adoption”*, and this is the case also for blockchain. Indeed, Dhingra et al. (2024) stated that *“top management support are the top-ranked or high-intensity challenges”* hindering blockchain adoption. Similar findings were reported by many other authors, such as Hussien et al. (2019), Kassab et al. (2021) and Shukla et al. (2021).

In conclusion, we can derive the following proposition:

***Proposition P8:*** Support from senior management is crucial for the successful implementation and adoption of blockchain

***Lack of regulations***

As stated by Toufaily et al. (2021), *“even though blockchain has the potential to positively impact many industries, some applications have called into question the legitimacy of the technology, given security and privacy concerns”*. However, currently no regulations exist to control such issues. Indeed, Toufaily et al. (2021) stated that *“regulatory uncertainty is a key challenge hindering blockchain applications and a wider adoption”* and that the *“absence of legal frameworks is stifling innovation”*. Similarly, Bai et al. (2022) reported that the *“immature regulation of this technology might raise concerns among stakeholders and become a barrier to the adoption of blockchain”*. Indeed, according to Janssen et al. (2020), laws and regulations can influence how fast the technology could develop.

In conclusion, we can derive the following proposition:

***Proposition P9:*** Regulations about data security and privacy laws need to be put in place by governmental bodies to support the widespread adoption of blockchain. These are however currently missing

***Lack of scalability***

*“Scalability refers to the ability of the system to sustain performance while growing and expanding, such as increasing the number of nodes, storage requirements and the response time per transaction as the network grows”* and it is *“a key technical challenge in blockchain adoption”* (Toufaily et al., 2021). More in details, Rana et al. (2022) stated that *“the blocks in the blockchain continue to grow with use and each transaction needs more time to be processed. The blockchain scalability problem relates to the fact that records (or blocks) in the blockchain are limited in size and frequency”*. Similarly, Hosseini Bamakan et al. (2021) stated that *“usages of blockchain are transaction-based, and therefore the databases used for this technology tend to rise at a rapid rate. The increasing size of databases causes the speed of record-searching and -accessing becomes decrease, which is highly inappropriate for the kinds of transactions where speed is crucial”*.

Hence, we can derive the following proposition:

***Proposition P10:*** Blockchains are characterized by restricted block size, which cannot be increased. This reduces transactions speed, which limits blockchain adoption by affecting the ability to handle growing transactions.

***Lack of standardization***

Due to the *“newness of blockchain”* (Govindan et al., 2023), many different ways of handling data collection and exchanges, transactions, validation, and security exist (Govindan et al., 2023; Kaur et al., 2024; Moretto and Macchion, 2022). However, *“process standardization can further advance the development of blockchain by providing internationally agreed ways of working”* (Kaur et al., 2024). Indeed, Hosseini Bamakan et al. (2021) stated that “to implement blockchain in this system (i.e. pharmaceutical sector) successfully there should be a suitable way of data storage of patients’ health record and information exchange between different systems takes part in blockchain application. In light of this, Toufaily et al. (2021) stated that *“companies, start-ups, public actors and industries need to work together to define standards (…) for advancing the blockchain and stay ahead of the technology curve to accelerate adoption”*. Indeed, *“although many pressures exist”* (Kouhizadeh et al., 2021), *“blockchain systems are not standardised”* (Upadhyay et al., 2021) and *“a lack of standard (…) is preventing”* the blockchain diffusion.

In conclusion, we can derive the following proposition:

***Proposition P11:*** Various blockchain applications are following different blockchain standards. The lack of standardization about transaction structures, validation, and security complicates the adoption of blockchain since companies lack clear rules and standards to follow

***Need for maintenance***

As stated by Rana et al. (2022), in addition to the cost of installation, also *“cost to maintain blockchain has a negative impact on the implementation and use of this technology (i.e. blockchain)”*. Similar findings are reported by other researches, who reported that the lack of maintenance could results in lower performances in terms of, e.g. transaction speeds, efficiency, and data security (Dhingra et al., 2024; Kouhizadeh et al., 2021; Rana et al., 2022). Industry reports and technical sources further clarify that blockchain maintenance involves a wide range of ongoing activities, including performance optimization, protocol updates, smart contract patching, node synchronization, and infrastructure scaling. For example, Rapid Innovation (2024) highlights the importance of timely protocol upgrades and regular system tuning to prevent performance bottlenecks and ensure network stability. Infuy (2024) discusses the need for infrastructure enhancements to support scalability and minimize latency as transaction volumes increase. Similarly, Orbaic (2024) emphasizes that without continuous technical updates and architectural adjustments, blockchain networks can become inefficient and unable to meet evolving operational demands. These insights illustrate that blockchain maintenance is a multifaceted, ongoing requirement. Failure to address it systematically can compromise the technology’s performance and security, ultimately undermining its effectiveness and long-term viability.

Hence, we can derive the following proposition:

***Proposition P12:*** Blockchain requires regular maintenance, otherwise it experiences slower transaction speeds, reduced efficiency, and higher data security issues.

***Lack of collaboration***

As stated by Bai et al. (2022), *“engagement and collaboration from all the (network) participants are vital”* for a successful blockchain implementation. Indeed, the lack of collaboration is reported by Saberi et al. (2019) to *“disturb the implementation of blockchain to create value”*. However, currently, “*collaboration (…) is seen as a considerable challenge”* (Toufaily et al., 2021). Specifically, they (Toufaily et al., 2021) better elaborated on this specifying that this is due to the low trust in the technology due to its newness and to the “lack of solid rules”.

In light of this, we can derive the following proposition:

***Proposition P13:*** A successful blockchain network requires the participation and commitment of all involved parties. It is however hard to convince all the involved parties and to ensure their cooperation, communication, and coordination

***Lack of knowledge on benefits***

As already mentioned in other challenges, the “*newness of blockchain”*, as defined it by Saberi et al. (2019), creates many setbacks for the technology. According to Asad and Popesko (2023), another challenge deriving from it is the lack of knowledge on blockchain benefits. This, in turn, according to Toufaily et al. (2021) limits blockchain adoption: *“a lack of top management knowledge of blockchain is hindering its adoption”*. Similar findings were found by, e.g., Kouhizadeh et al. (2021) and Govindan et al. (2023).

In light of this, we can derive the following proposition:

***Proposition P14:*** Blockchain is new and in a developmental phase. Therefore, managers do not know what would be the benefit achievable and hence doubt about its adoption

***Lack of skilled personnel***

As stated by Mahjoub et al. (2022), there is *“an acute shortage of skilled developers and a lack of expertise”*, which *“represents an important obstacle in wider deployment of this technology (i.e. blockchain)”*. Similarly, Toufaily et al. (2021) defined *“the skills, competencies and talents in the organization as a crucial challenge for adoption”*. Indeed, *“without a solid grasp of the intricacies of blockchain technology, there is a higher likelihood of poorly designed or executed blockchain projects”*.

In light of this, we can derive the following proposition:

***Proposition P15:*** There is limited amount of personnel skilled in blockchain, which is instead needed to fully exploit the benefits of blockchain.

***Privacy concern***

As reported by Pattanayak et al. (2024), blockchain, as a distributed ledger, is designed to disclose more data to other participants than traditional centralized databases. In light of this, Toufaily et al. (2021) reported that *“overcoming privacy and confidentiality issues constitutes one of the key challenges to widespread blockchain adoption,”* pointing to the openness of public blockchains as a major concern. In public blockchain systems, transaction data is fully visible to all participants, raising significant privacy concerns. For instance, the Wilson Center notes that the public nature of blockchain transactions can lead to privacy concerns, as sensitive information like financials or health records are exposed to the public (Wilson Center, 2023). While this issue is most apparent in public blockchain systems, where transaction data is fully visible to all participants, privacy concerns are not entirely absent in private or permissioned blockchain settings. In fact, industry sources note that even in private blockchains—commonly used in enterprise supply chains—organizations can still face the risk of exposing sensitive business information to other firms operating at different stages of the supply network (Trend Micro, 2023; A-LIGN, 2023). This internal visibility, while beneficial for transparency and traceability, can result in unintended competitive exposure if not carefully managed. Therefore, while blockchain offers advantages in terms of transparency and data immutability, privacy concerns remain significant, particularly in contexts where transaction data may be visible to third parties within the same ecosystem.

In light of this, we can derive the following proposition:

***Proposition P16:*** Blockchain transactions are recorded on a public database accessible to anyone. This gives rise to privacy concerns.

***Workforce resistance***

As stated by Queiroz and Fosso Wamba (2019), the *“individual (employee’s) motivation to accept and use a new technology is related to his/her perception of some advantages (including the useful level) of the technology in his or her job routine”*. Since, as discussed above, there is a limited knowledge on the benefits of blockchain, Lohmer and Lasch (2020)reported *“staff difficulties”* to be one of the major barriers to blockchain adoption. Similarly, Hosseini Bamakan et al. (2021) stated that “accepting this technology (i.e. blockchain) that is so different from the traditional work methods never comes easy. Although the pharmaceutical industry is slowly moving towards blockchain, it takes a long time to use this technology completely.” In light of this, Kouhizadeh et al. (2021) suggested to *“prepare employees for blockchain implementation”*.

***Proposition P17:*** Employees are reluctant to adopt blockchain and to change their processes to accommodate its implementation

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