ABSTRACT
Blockchain and distributed ledger technologies are gaining the interest of the academy, companies, and institutions. Nonetheless, the path toward blockchain adoption is not straightforward, as blockchain is a complex technology that requires revisiting the standard way of addressing problems and tackling them from a decentralized perspective. Thus, decision-makers adopt blockchain technology for the wrong reasons or prefer it to more suitable ones. This work presents a decision framework for blockchain adoption to help decision-makers decide whether blockchain is applicable, valuable, and preferable to other technologies. In particular, The decision framework is composed of a small set of questions that can be answered from a managerial standpoint and that do not require a deep technical knowledge of blockchain-related topics.

Keywords
blockchain adoption · blockchain suitability · decision making · decision flowchart · when to use.

1 Introduction
At present, companies are undergoing radical transformations based on information sharing and digitization, known collectively as the Industry 4.0 revolution [Fakhri et al., 2020]. Such a revolution is driven by the recent technological advancements in physical monitoring, data elaboration, virtualization, and automation technologies [Bai et al., 2020, Boccia et al., 2021, Caselli et al., 2022, Padda et al., 2021]. On one side, data acquisition and storage is becoming cheaper and more accurate [Capocasale et al., 2021]; on the other, peer-to-peer technologies such as blockchain [He et al., 2022] and the Interplanetary File System [Capocasale et al., 2022] are transforming existing business paradigms [Perboli et al., 2018].

Blockchain creates trust among non-trusting parties without relying on intermediaries. A blockchain is composed of a network of nodes managing a shared and distributed database: tampering attempts are prevented by replicating the state of the database on each node. Smart contracts are independently executed by each node and are used to alter the state of the database. Thus, by leveraging the tamper-resiliency of the blockchain, smart contracts could enhance the fairness of critical processes, protect valuable resources, and automate business operations. Given the relevance of such topics [Aringhieri et al., 2022, Serrano, 2022], smart contract-based alternatives to existing services are surging in multiple sectors, including finance [Pavlova, 2020], insurance [Gatteschi et al., 2018a], logistics [Pan et al., 2021], energy [Ruffini et al., 2022, Khan et al., 2021], and more.

Nonetheless, blockchain is a complex technology that introduces many compromises and issues at all technical, legal, and economic levels. Thus, decision-makers often lack the necessary knowledge to make informed decisions on blockchain adoption, and misconceptions are widespread in the field [Schneider and Azan, 2022]. Unsurprisingly, blockchain is often chosen for the wrong reasons or is preferred to better technologies [Belotti et al., 2019, Halaburda, 2018, Carson et al., 2018, Labazova et al., 2019]. Consequently, many blockchain projects do not last long or fail to fulfill the original goals [Kaufman et al., 2021]. In this context, it is essential to develop standards and tools to simplify the managerial decision process on blockchain adoption.

We contribute to the current body of knowledge by making the following contributions:

• we propose a decision flowchart for blockchain adoption that helps decision-makers understand when blockchain is applicable, valuable, and preferable to other solutions. The framework does not require
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any deep technical knowledge of blockchain technology and can be effectively employed by decision-makers with different backgrounds;

• we discuss the rationale behind each of the decision drivers of our framework to shed some light on some of the hidden caveats of blockchain technology, as they are not sufficiently discussed in the existing literature.

The remaining part of this study is structured as follows: Section 2 briefly describes the blockchain technology and presents a summary of the related works; Section 3 describes the blockchain adoption decision framework; Section 4 concludes the study.

2 Background

This section summarizes the main concepts related to blockchain. Moreover, this section includes a summary of the related works.

2.1 Blockchain

Blockchain is a technology that enables data sharing among non-trusting parties. Blockchain allows for solving trust issues without leveraging trusted third parties. Blockchain is composed of a network of peers that share a common database. The shared database is a ledger, as data can only be appended to it. Each peer manages its copy of the ledger independently from the others. Thus, peers can maliciously alter their copy, but not the global state of the ledger, which is decided based on what is stored in the majority of the copies [Zheng et al., 2018, Luo et al., 2022]. We assume a uniform distribution of voting power among the peers to simplify the discussion. However, when we refer to the majority of the peers, we mean the majority of the voting power.

Blockchains can be categorized according to their governance model as follows [Buterin, 2015, Lin and Liao, 2017].

• **Public**—Any peer can join the blockchain system and gain voting power. Public blockchains solve trust issues among their participants, as peers can autonomously validate transactions.

• **Consortium**—The blockchain system is managed by some well-identified peers who can set the rules for interacting with the ledger and gaining voting power. Consortium blockchains solve trust issues among the consortium members.

• **Fully private**—A single peer manages the blockchain system. Thus, the system is not decentralized.

2.2 Problem Statement

Many real-world systems are intrinsically decentralized. For example, supply chains are composed of numerous companies, and the behavior of each one affects the performance of the whole supply chain. Thus, it is logical to manage supply chains in a decentralized way by allowing each company to vote on the best strategy to improve the performance of the whole supply chain.

The introduction of blockchain technologies has created the opportunity to decentralize the management of data. Thus, blockchain has gained adoption in all those intrinsically decentralized systems that previously relied on trusted third parties. Nonetheless, blockchain is a complex technology and introduces many hidden compromises and issues. Moreover, decision-makers often lack the necessary technical knowledge to make informed decisions on blockchain adoption. Thus, blockchain is often adopted for the wrong reasons or is preferred to better technologies [Belotti et al., 2019, Halaburda, 2018, Carson et al., 2018, Labazova et al., 2019].

To solve this problem, we created a framework that helps decision-makers understand when blockchain is applicable, valuable, and preferable to other solutions. The framework does not require a deep technical knowledge of blockchain technology and can be effectively employed by decision-makers with different backgrounds.

2.3 Related Works

According to Ref. [Almeshal and Alhogail, 2021], blockchain suitability frameworks can be divided into three categories: decision models, conceptual frameworks, and decision flowcharts.

Decision models use mathematical models to decide on blockchain adoption. For example, BAF is a framework for determining the ideal blockchain solution based on a weighted evaluation of detailed user requirements [Gourisetti et al., 2020].

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Conceptual frameworks identify the factors to consider in adopting blockchain technologies based on the practical experience of researchers. For example, ten technology-driven factors are considered by the framework proposed in Ref. [Scriber, 2018]. Other authors included non-technological factors (e.g., environmental considerations, such as regulations) [Clohessy et al., 2020, Labazova, 2019]. Open-ended questions that should be addressed when considering blockchain adoption are proposed in Ref. [Angelis and Ribeiro da Silva, 2019].

Decision flowcharts are based on graphs where nodes represent closed-ended questions and edges represent the related answers. Users are led to a decision by the path dictated by the answers they pick. Many authors adopted such a strategy in the literature. A study proposed a multi-step framework to decide on blockchain adoption and the type of blockchain needed [Peck, 2017]. Others deepened the discussion by providing some guidelines on implementing working solutions [Belotti et al., 2019], considering the security threats of using blockchain [Puthal et al., 2021], and analyzing real-world use cases [Hassija et al., 2021, Wust and Gervais, 2018, Gatteschi et al., 2018b]. A framework explicitly designed for managers is proposed in Ref. [Challener et al., 2019]. Multiple frameworks were analyzed and condensed into a single one in Ref. [Koens and Poll, 2018]. However, we do not agree with some of the decision drivers proposed in all such works. For example, requiring the presence of multiple writers is unnecessary: a group of entities may need to record in a tamper-proof way what is written by a third one. In such a case, a blockchain could be a viable solution, as the multiple record keepers could prevent the writer from altering past data. Thus, blockchain adoption should be driven by the presence of multiple decision makers (the keepers can decide which data are alterable), not multiple writers.

Ref. [Lo et al., 2018] describes a framework composed of seven main questions and four subquestions. However, a good technical understanding of the technology is necessary to answer some of the proposed questions. A ten-step decision framework is proposed in Ref. [Pedersen et al., 2019]. The framework is very useful as it considers many aspects that are ignored in similar works.

Finally, some authors proposed decision frameworks for blockchain adoption that are tailored to specific use cases (e.g., logistics [Ar et al., 2020, Ganeriwalla et al., 2018, Hribernik et al., 2020] and the construction industry [Hunhevicz and Hall, 2020]).

Table 1: The table resumes the literature on decision frameworks for blockchain adoption based on decision flowcharts. The table highlights the common adoption questions between our framework and those proposed in the literature.

| Ref.                     | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 |
|--------------------------|----|----|----|----|----|----|----|----|----|-----|-----|
| [Hunhevicz and Hall, 2020] | No | Yes| No | No | No | Yes| No | No | No | No  | No  |
| [Wust and Gervais, 2018]  | No | Yes| No | No | No | Yes| No | No | No | No  | No  |
| [Belotti et al., 2019]   | No | Yes| No | No | No | Yes| No | No | No | No  | No  |
| [Puthal et al., 2021]    | No | Yes| No | No | Yes| No | No | Yes| No | Yes | No  |
| [Hassija et al., 2021]   | No | Yes| No | No | Yes| No | No | No | No | No  | No  |
| [Pedersen et al., 2019]  | Yes| Yes| No | No | Yes| No | No | Yes| No | No  | No  |
| [Koens and Poll, 2018]   | No | Yes| No | No | No | No | No | No | No | No  | No  |
| [Peck, 2017]             | No | Yes| No | No | No | No | No | No | No | Yes | No  |
| [Gatteschi et al., 2018b]| No | Yes| No | No | Yes| No | No | No | No | Yes | Yes |
| [Lo et al., 2018]        | Yes| Yes| No | No | Yes| No | Yes| No | Yes| No  | Yes |
| [Challener et al., 2019] | Yes| No | No | No | Yes| No | Yes| No | Yes| No  | Yes |

3 Blockchain Adoption Decision Framework

This section describes our decision framework for blockchain adoption, which is graphically summarized in Fig. [1]. Before introducing our approach, we want to make a few important remarks.

- Blockchain is meaningful when decentralized governance is required. Even though the locution distributed ledger technology has gained adoption, decentralization is what matters, not distribution [Come-from-Beyond, 2020].
- Blockchain is inefficient and should be used only when necessary. Blockchain is the only technology allowing for managing a database in a decentralized fashion. However, if the database can be managed by a single entity, other technological solutions are better [Challener et al., 2019].

As a consequence of the previous points, fully private blockchains have little to no use, in our opinion. They can be employed to prevent accidental data modifications, but non-distributed ledgers are more efficient (e.g., ImmuDB [Paik, ...].
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Thus, employing fully private blockchains can be a good marketing strategy but not a good technological one. For example, central bank digital currencies [Benedetti et al., 2022] should not leverage blockchain if they are managed by a single entity (the central bank). Consequently, our framework deals with the suitability of public or consortium blockchains.

3.1 Q1: Should Multiple Actors Have Decision Power?

The most important thing to consider when deciding on blockchain adoption is whether or not the system is decentralized. If decision power is not shared among multiple actors, centralized solutions (e.g., distributed databases) should be preferred: according to the scalability trilemma, decentralization comes at the cost of scalability or security [Schaaf et al., 2021]. Thus, compared to the blockchain, centralized solutions are more scalable and secure.

It is important to underline that having decision power means having voting power to validate write attempts in the context of blockchain. Blockchain can be described as a database that can be altered through a majority-based voting scheme. Thus, blockchain allows multiple actors to vote and decide which are valid database modifications. Remarkably, blockchain does not offer the same guarantees on reading attempts, as a single malicious actor could leak the contents of the database.

Finally, we underline that validating writing attempts does not imply having writing rights. For example, in a trial, the judge decides what is admissible as evidence but cannot produce evidence. As discussed in Sec. 2.3, this remark is one of the main points of differentiation between our work and the existing literature.

3.2 Q2: Do the Actors Trust a (Third) Party?

If an external entity or one of the actors is particularly trustworthy, the actors may be comfortable delegating their decision power to such an entity. In such a case, centralized solutions managed by the trusted party are better alternatives to blockchain for the same reasons outlined in the previous section. Vice versa, blockchain is a viable solution when no single party is trusted by all the actors. Almost all the decision frameworks present in the literature include this decision driver, which remarks its importance.

3.3 Q3: Do the Actors Trust the Majority?

Blockchain does not solve trust issues completely: a precondition for using blockchain technology is that the majority of the actors are trustworthy [Capocasale and Perboli, 2022]. Thus, blockchain should only be used if actors are unlikely to collude. Otherwise, the malicious majority could tamper with or rewrite the database (51% attack) [Hao, 2022]. Unfortunately, the literature has not given enough weight to such a relevant decision driver. We strongly encourage decision-makers to carefully consider the likelihood of 51% attacks before adopting blockchain, as such attacks are not uncommon [Martin, 2020, Voell, 2021]. Launching 51% attacks is easier on small networks as it requires fewer actors to collude. Moreover, some blockchains may be attacked by an even lower percentage of colluding peers as a consequence of the voting protocol in use. Thus, particularly in consortium blockchains, the presence of a trustworthy (super)majority must be carefully checked.

3.4 Q4: Are the Actors Equally Influential?

Actors should detain a similar decision power so that blockchain may become a viable solution: if one of the actors has strong leverage against the others, such an actor is likely to enforce its own centralized solution. In such a scenario, blockchain is unlikely to be successfully adopted, as the influential actor has no reason to share the control of the database. Moreover, even if a blockchain were used, the influential actor could force others to align with its own decisions. Thus, the majority would probably be untrustworthy.

Porter’s five forces analysis [Porter, 2008] is useful to determine the influence of the various actors. In particular, studying the bargaining power of customers and suppliers can be helpful in determining the balance of power among actors, which could provide insights into the applicability of blockchain technology.

For example, Amazon [Ritala et al., 2014] manages one of the biggest marketplaces in the world. Sellers have many advantages in selling their products on Amazon, including increased visibility, international expansion, and storage and shipping services. Nonetheless, sellers need to abide by Amazon’s policies. Such policies are not negotiable, as Amazon has the upper hand in terms of bargaining power. In such a scenario, a blockchain solution is unlikely to be adopted, as Amazon can force the sellers to rely on Amazon’s managed database. Conversely, blockchain could be adopted for the creation of a unified marketplace between Amazon and Alibaba [Havinga et al., 2016], as they are both e-commerce giants with similar bargaining power.
3.5 Q5: Is data sharing advantageous for the actors?

Blockchains are shared databases. Actors that are not interested in sharing their data or receiving others’ data are unlikely to join a blockchain network. Data that is not meant to be shared should be stored in centralized databases, as the database manager retains total power over the stored data. Nonetheless, blockchain can be leveraged in some use cases that require non-straightforward data-sharing approaches. We identified a few of them: partial sharing, delayed sharing, conditional sharing, and proof sharing.

Partial sharing refers to the necessity of sharing data with only some of the actors. In such a case, the best approach is to create a separate blockchain involving only the selected receivers. However, for costs or practicality, actors may prefer to store encrypted data into a single blockchain involving all the actors, and share the decryption key with only the selected receivers. Thus, encrypted data are stored in a tamper-proof database and shared with all the actors, but only who know the decryption key can recover the original data. Different encryption/decryption keys can be used to disclose data to different actor subsets.

Delayed sharing refers to the possibility of sharing data in the future while guaranteeing that it is not altered in the meanwhile. For example, some countries disclose classified documents after a certain amount of time. By storing encrypted documents in a blockchain and successively disclosing the decryption key, it is possible to guarantee the authenticity and integrity of the documents at disclosure time.

Conditional sharing refers to the possibility of sharing data only if a certain event occurs. For example, a company may have some confidential data that have to be shared only in case of litigation. Similar to the delayed sharing case, it is possible to use blockchain to guarantee the authenticity and integrity of encrypted data and successively reveal the decryption key, if necessary. Interestingly, if the event never occurs, blockchain is used to store data that is never disclosed.

Proof sharing refers to the possibility of not sharing the data directly but a proof computed on the data (e.g., zero-knowledge proofs [He et al., 2022] or a fingerprint of the data (e.g., the hash of the data [Zemler, 2019]). There are many reasons for using such approaches, including guaranteeing the integrity of the original data and minimizing the disclosure of information. Interestingly, blockchain is still used to share data, even if not in its original form.

3.6 Q6: Have the Actors Aligned Interests to Cooperate?

Blockchain systems are based on majority consensus, which can be reached if actors are incentivized to behave correctly according to some common rules. If actors do not have aligned interests, they are unlikely to join a blockchain network, and even if they did, they would be unlikely to follow the same rules. Thus, blockchain is applicable only if cooperating is advantageous for the actors.

Often, public blockchains offer economic incentives to align the actors’ goals and persuade them to behave correctly. In consortium blockchains, other forms of incentives are common. Often, such incentives come indirectly in the form of business opportunities and cost savings. In logistics, for example, sharing data can be beneficial for demand forecasting and paperwork reduction [Perboli et al., 2020]. Moreover, by tracking assets along the whole supply chain, it is possible to easily assign responsibilities to actors and reduce the risk of litigation [Perboli et al., 2020]. Thus, the actors of a supply chain may share a common interest that can enable and sustain long-term cooperation.

3.7 Q7: Have Misbehaving Actors Opposed Interests?

Even if actors have a strong motivation to cooperate, they might have an even stronger motivation to cheat, which is particularly true when opportunities to make quick and easy gains arise. For this reason, it is important to ensure that misbehaving actors have conflicting goals so that one’s gains would mean another one’s loss. In this way, the risk of majority collusion attempts is minimized, as actors should behave against their own interests to corrupt the system.

We examine the example of Bitcoin [Lánský, 2017]. Each Bitcoin holder has good motivation to misbehave and create new Bitcoins, as this would increase the holder’s purchasing power. However, creating new Bitcoins inflates the existing supply, reducing the purchasing power of each Bitcoin. Consequently, Bitcoin holders want to create Bitcoin for themselves while preventing others from doing the same. Thus, collusion attempts are unlikely, as Bitcoin holders have conflicting interests when misbehaving.

We examine the example of a group of friends betting on the winner of a horse race. For simplicity, we assume that each friend picks a different horse. If the friends do not want to rely on trusted third parties, they could rely on a smart contract to collect the money in advance and then forward them to the winner: the verifiability and tamper-proof property of the blockchain would guarantee the correct handling of the bet. Thus, blockchain may seem a good solution. Unfortunately, in this scenario, the majority of the friends will lose the bet and will likely collude to take back their
money instead of forwarding the prize to the winner. Given that blockchain decisions (including the behavior of smart contracts) are based on majority agreements, the winner of the bet will not receive the prize. Thus, blockchain should not be employed when cheating attempts favor the majority.

3.8 Q8: Are All the Relevant Actors Involved in the Management of the System?

By leveraging blockchain, decisions can be taken through majority voting instead of being delegated to a trusted third party. Nonetheless, a blockchain system is a third party for the actors that do not have voting power. Thus, blockchain does not offer any additional trustworthiness guarantees to them, and blockchain members should not expect entities to acknowledge the trustworthiness of third-party managed blockchain systems.

In logistics, for example, consortium blockchains are often used to facilitate the exchange of data among supply chain companies [He et al., 2022]. Final retail consumers, however, are rarely part of the consortium, as they lack the means, the technical knowledge, the time, the economic incentives, and the will to be involved in the consortium. To them, logistic blockchains are trusted third parties. Thus, supply chain companies should not join a blockchain system solely to increase data transparency for the final consumers, as consumers have no reason to trust the data stored in a blockchain more than the data provided by their retailer. Thus, blockchain systems should be used to create value for their participants, not external entities.

3.9 Q9: Are the Actors Sufficiently Autonomous?

The resiliency of blockchain is proportional to its decentralization. Thus, actors should be as autonomous and independent as possible to guarantee sufficient resilience to errors and tampering attempts. If too many actors needed to rely on others to code smart contracts, keep an updated copy of the ledger, participate in the voting process, and validate transactions, the blockchain would become supposedly decentralized but substantially centralized. In such a condition, blockchain does not offer any benefits over centralized systems but still imposes significant scalability drawbacks. Thus, blockchain should not be used if true decentralization cannot be guaranteed. In particular, decentralization cannot be improved by increasing the number of blockchain nodes managed by each actor, as distribution and decentralization are different concepts [Come-from-Beyond, 2020].

3.10 Q10: Should Retroactive Data Manipulations Be Prevented?

If a blockchain system is sufficiently decentralized, data stored in a blockchain ledger can be considered tamper-proof. Thus, data cannot be manipulated after insertion, and updates are only possible by appending a newer version of the data to the ledger. Nonetheless, blockchain would keep both versions, allowing actors to track changes. Thus, blockchain is a good solution if it is important to prevent retroactive data manipulations. Nonetheless, if such a property is not relevant, standardizing the data exchange protocols among the actors is enough to share data efficiently. Thus, if preventing retroactive data manipulations is not a priority, each actor should manage its centralized database and use a standard data sharing protocol to exchange information with the other actors. Interestingly, blockchains are often adopted solely to enforce standardization [Olszewski, 2019].

3.11 Q11: Should Proactive Data Manipulations Be Prevented?

As previously discussed, blockchain can prevent retroactive data manipulations. Nonetheless, blockchain can rarely prevent proactive data manipulations (i.e., manipulations that happen before the data is stored in the blockchain). In particular, oracle data can hardly ever be verified and validated, as such data often convey information about the physical world [Capocasale et al., 2021]. In logistics, for example, the temperature of a frozen product at a given time is likely measured by the actor that is handling that product at that time. The other actors cannot measure such a temperature, as they lack physical possession of the product. Thus, they need to rely on and cannot verify the accuracy of the measure of the handling actor. In such a scenario, blockchain is prone to the garbage in, garbage out problem. Conversely, Bitcoin transactions are fully digital, and each peer can independently verify them: by keeping a registry of the balance of each Bitcoin holder, each peer can determine who has enough coins to spend. Nonetheless, very few use cases can be modeled without relying on oracles, which limits blockchain usefulness when proactive data manipulations must be prevented.

4 Conclusion

Interest in blockchain technology is rising among all individuals, countries, and companies. Nonetheless, the path toward blockchain adoption is not straightforward, as blockchain is a complex technology that requires revisiting the
standard way of addressing problems and tackling them from a decentralized perspective. Thus, decision-makers may adopt blockchain technology for the wrong reasons or prefer it to more suitable ones.

This work presented a decision flowchart that can help readers to decide on blockchain adoption. We considered various decision drivers that should help the readers understand whether blockchain is applicable, valuable, and preferable to other technologies. We believe that our framework can be particularly useful to decision-makers, as it includes many decision drivers that are overlooked by other similar works in the literature. Moreover, our framework can be employed without deep knowledge of blockchain, as the concepts are discussed from a high-level perspective. Thus, we believe that it can be effectively used by managers to drive blockchain adoption in their companies without wasting time studying the very articulate blockchain technology.

Our framework underlines the correlation between decentralization and the security of blockchain systems. The main takeaway is that blockchain should only be employed if sufficient decentralization can be guaranteed, which is rarely the case.

Future work will be focused on extending the current framework to provide support for additional questions that may arise following blockchain adoption, including feature selection, platform binding, cost considerations, and more.

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Figure 1: The proposed decision framework for blockchain adoption