ARTICLE IN PRESS

Government Information Quarterly xxx (xxxx) xxx

Contents lists available at ScienceDirect

Government Information Quarterly

journal homepage: www.elsevier.com/locate/govinf

Blockchain governance in the public sector: A conceptual framework for public management

Evrim Tan [*], Stanislav Mahula, Joep Crompvoets

Public Governance Institute (PGI), KU Leuven, Belgium

ARTICLE INFO

Keywords:
Blockchain
Distributed ledger technology
Governance
Public management
DAO

ABSTRACT

A key challenge behind the adoption of blockchain in the public sector is understanding the dynamics of blockchain governance. Based on a systematic literature review, this article analyzes different approaches to blockchain governance across disciplines and develops a comprehensive conceptual framework for the study of blockchain governance decisions in the public sector. The framework clusters nine types of governance decisions (infrastructure architecture, application architecture, interoperability, decision-making mechanism, incentive mechanism, consensus mechanism, organization of governance, accountability of governance, and control of governance) into three levels of analysis (micro, *meso*, and macro-levels). Drawing on public management theories and concepts, the article elucidates the implications of various governance choices in each level of governance and provides a primer for researchers and policy practitioners on the design of blockchain-based systems in the public sector.

1. Introduction

It is been more than a decade since the seminal paper by Nakamoto (2008) introduced Bitcoin and its underlying technology, i.e. blockchain. Since 2008, blockchain has evolved as a general-purpose technology and found various areas of applications where a 'trust' problem is observed in a system of transactions. The public sector has become a principal area of application, in which governments and other actors have announced more than two hundred use cases all around the world.[1] Digital currency/payments, land registration, identity management, notarization, supply chain traceability, healthcare, education, corporate registration, data management, auditing, energy market, taxation, voting, and legal entities management are some areas where blockchain is currently being tested for public services.

Notwithstanding this widespread interest, the actual implementation of the technology in the public sector remained limited.[2] Previous studies highlighted several adoption challenges such as lack of regulation, security, and privacy concerns, insufficient and lack of interoperable infrastructure, inefficient and energy- costly transactions, the need for value-driven transitions in administrative processes, and last but not the least, the absence of effective governance models (Janssen, Weerakkody, Ismagilova, Sivarajah, & Irani, 2020; Ølnes, Ubacht, & Janssen, 2017; Zachariadis, Hileman, & Scott, 2019). Multiple studies identified governance as a key challenge for the implementation of blockchain in the public sector (Atzori, 2017; Meijer & Ubacht, 2018; Ølnes et al., 2017) and some notable studies explore the implications of blockchain in public governance (Atzori, 2017; Beck, Müller-Bloch, & King, 2018; de Filippi, Mannan, & Reijers, 2020; Werbach, 2018; Zachariadis et al., 2019). Nonetheless, it appears that blockchain governance remains one of the most controversial aspects for public sector organizations and a systematic analysis tool is needed to address governance challenges for the design, operation, and maintenance of blockchain-based systems (Janssen et al., 2020; Ølnes et al., 2017). As a technology whose most salient feature is to build confidence in governance processes without a need of a trusted third party, understanding what to govern (or not to govern) and how to govern is fundamental to adopt blockchain in the public sector.

In this article, we conduct a systematic literature review to map out the existing conceptual approaches toward blockchain governance in different disciplines and synthesize them into a comprehensive

* Corresponding author.
E-mail addresses: evrim.tan@kuleuven.be (E. Tan), Stanislav.mahula@kuleuven.be (S. Mahula), joep.crompvoets@kuleuven.be (J. Crompvoets).

[1] According to the European Blockchain Observatory, there are 229, and according to Airtable, 208 use cases registered in the public sector as of November 2020.

[2] According to European Blockchain Observatory, 30 use cases and according to Airtable, 17 use cases are registered as live and in production as of November 2020.

https://doi.org/10.1016/j.giq.2021.101625
Received 6 May 2021; Received in revised form 14 July 2021; Accepted 24 August 2021

conceptual framework for the study of blockchain governance. We apply this framework to the public sector context to explore the implications of different design choices in blockchain governance. Specifically, we address the following questions: (1) what governance decisions are needed to design a blockchain-based system in the public sector?, and (2) how contextual factors in the public sector may shape available choices in blockchain governance? Through these research questions, we aim to elucidate how blockchain governance can impact the relationship between the governed and those governing, and how this technology can be used to provide innovative public services.

The article is structured in six subsequent sections. In Section 2, we present the theoretical framework for blockchain governance. Section 3 presents the methodological choices and the findings from the systematic literature review. Section 4 presents the conceptual framework for blockchain governance and applies it in the public sector. In the last section, we present our concluding remarks and share recommendations for further research areas.

2. Theoretical framework

Blockchain is part of distributed ledger technologies (DLT) that give users confidence that archived information has not been tampered with (Beck et al., 2018). The main difference between blockchain and DLT is that the latter is a technology for the management of a distributed database, whereas the former is a confidence-building technology through the means of consensus mechanisms and sequential registry of information in a chain-type formation.

Theoretically, by creating an autonomous, transparent, and secure distributed system, blockchain may enable the removal of intermediaries in public management as trustees replacing them with an algorithmic confidence system (De Filippi et al., 2020). This technological feature of blockchain is what makes blockchain governance contradictory and convoluted for the public sector. In that regard, two diverging views appear in the literature. The first view is that blockchain allows transparency, integrity, and traceability of data to authenticate the information, and thereby reduces the transaction costs and enhances the efficiency of public services (Beck et al., 2018; Ziolkowski, Miscione, & Schwabe, 2020). The second view, on the other hand, perceives blockchain as a disruptive technology that allows permissionless transactions in a truly decentralized manner, whereby the government loses its purpose as primus inter pares (Pierre & Peters, 2000) in the public sector, as a centralized authority is no longer required to coordinate, mitigate or govern public services (Atzori, 2017; Miscione, Ziolkowski, Zavolokina, & Schwabe, 2018).

An additional level of complexity is that blockchain as a technology re-establishes the importance of trust and legitimacy in the initial policy and system design phase instead of the implementation. In both permissioned and permissionless blockchains, the rules of transactions are set at the design phase, and once a decision is made a change in the system requires the consent of authorized users. Furthermore, blockchains can confirm the genuineness of a transaction but whether a given input in a transaction is genuine or the transaction rules are fairly established is beyond the technical scope of blockchains. Therefore, 'who will be authorized to make changes in the system?', and 'what are

Table 1
Coding scheme.[a]

Category	Codes	Subcodes	References
Micro level	Infrastructure architecture (37)	public/ private (13), permissionless/−ed (12); blockchain protocol, blockchain architecture, hyperledger fabric network, chaincode, backend, frontend, system development, system updates, security, decentralization, immutability, traceability	Alketbi, Nasir, and Abu Talib (2020); Angarita, Dejous, and Blake (2019); Carvalho, Merhout, Kadiyala, and Bentley (2021); Daluwathumullagamage and Sims (2020); Diniz, Cernev, Rodrigues, and Daneluzzi (2020); Dobler, Ballandies, and Holzwarth (2019); Ertz and Boily (2019); Flood and McCullagh (2020); Franke, Schletz, and Salomo (2020); Halaburda and Mueller-Bloch (2020); John and Pam (2018); Meunier (2018); Miscione, Goerke, Klein, Schwabe, and Ziolkowski (2019); Miyachi and Mackey (2021); Ozdemir et al. (2020); Razzaq et al. (2019); Rikken et al. (2019); Schaffers (2018); Singh and Michels (2018)
	Application architecture (14)	smart contract (4), DAO (4), application (2), dApps, oracles, autonomous organization (2)	
	Interoperability (5)	standards (2), standardization, interoperability, measures	
Meso level	Decision-making mechanism (33)	on-chain/off-chain (14), community governance (2), voting (2), lobbying, idea-forming, enlighten despotism, open governance model, chain-governance, liquid democracy, delegative democracy, quadratic voting, on-chain governance, reputation-based governance, democratic, representative, decision-making, communication; participation in decision-making,	Allen and Berg (2020); Beck et al. (2018); Benedict (2019); Bertolami and Francisco (2021); Brinkmann and Heine (2019); de Filippi et al. (2020); Dimitropoulos (2020); Dirose and Mansouri (2018); Dobler et al. (2019); Dursun and Üstündağ (2021); Erbguth and Morin (2019); Hermstrüwer (2019); Hsieh, Vergne, and Wang (2018); John and Pam (2018); Kaal (2020); Kavanagh and Ennis (2020); Kim and Huh (2020); Nicolae-Bogdan-Cristian, Luca, and Pungila (2020); Parkin (2019); Pimentel and Boulianne (2020); Reyes (2021); Shah and Jansen (2021); Tozzi (2019); Trbovich (2019); Van Pelt et al. (2021); Y. Wang (2019); Werbach (2018, 2020); Zachariadis et al. (2019); Ziolkowski et al. (2020)
	Incentive mechanism (8)	incentives (5), incentive structure, nature of incentives, incentives intensity	
	Consensus mechanism (14)	consensus mechanism (6), consensus models (e.g. PoW, PoS) (5), consensus (2); consensus making process.	
Macro level	Organization of governance (21)	(de)centralized (7), distributed (3), hierarchy, hetrarcy, levels of decentralization, roles, membership, formation, central, shared, semi-centralized (supernodes), implementation of a governmental process, roles in collective decision-making	Alketbi et al. (2020); Allen et al. (2020); Allen and Berg (2020); Allessie, Janssen, Ubacht, Cunningham, and van der Harst (2019); Arisi and Guarda (2020); Bagloee et al. (2021); Beck et al. (2018); Benedict (2019); Brinkmann and Heine (2019); Chen et al. (2021); Daluwathumullagamage and Sims (2020); Dimitropoulos (2020); Diniz et al. (2020); Dirose and Mansouri (2018); Erbguth and Morin (2019); Franks (2020); Gruin (2020); Hsieh et al. (2018); Jia and Zhang (2018); John and Pam (2018); Kaal (2020); Katina, Keating, Sisti, and Gheorghe (2019); Lacity (2018); Meijer and Ubacht (2018); Miscione et al. (2019); Nicolae-Bogdan-Cristian et al. (2020); Ølnes et al. (2017); Paech (2017); Rikken et al. (2019); Rodrigues, Meirelles, and Cunha (2018); Schaffers (2018); Shah and Jansen (2021); Shermin (2017); Trbovich (2019); Trump, Florin, Matthews, Sicker, and Linkov (2018); Van Pelt et al. (2021); Yeung and Galindo (2019); Zachariadis et al. (2019); Ziolkowski et al. (2020)
	Accountability of governance (47)	accountability (5), rules in governance (4), forking (4), code-is-law/ lex cryptographia/ governance by code (4), quality assurance, dispute/conflict resolution (2), override (2), rule change(2), status recognition/identity of parties (2), algorithmic rules, on-chain protocol, off-chain development, contract framework, coordination mechanism, normative basis, policies, procedures, improvement proposals, community borders, rules of recognition, rules of change, adjudication concerning the violation of primary rules, collective scope, prohibitive approach, prudential enthusiasm, liberalized approach, data protection, good governance, transparent governance, citizen engagement	
	Control of governance (16)	decision rights (6), control mechanisms (informal/formal) (3), control of blockchain/infrastructure (3), control of the market through blockchain, control systems, direction, oversight.	

[a] The frequency of the codes is indicated in the brackets.

the rules/procedures to follow in the change of the system?' are key governance considerations for blockchain-based systems. Vili Lehdonvirta calls these inherent contradictions of blockchain governance as 'governance paradox' as once you address these problems of governance, blockchain loses its value over conventional technologies and means where a trusted central party enforces the rules because you are already trusting some organization or process to make the rules (Werbach, 2018).

Furthermore, theoretical foundations of what blockchain governance entails, and the key decisions associated with it appear to be varying within different disciplines. For instance, in the information and computer science literature, approximating to the open-source system (OSS) and Internet governance, blockchain governance often focuses on the way decision rights, incentives, and accountabilities are arranged in a blockchain network to encourage desirable behavior in the use of resources (e.g. Beck et al., 2018; Rikken, Janssen, & Kwee, 2019; Van Pelt, Jansen, Baars, & Overbeek, 2021). Especially, in public permissionless blockchains, game-theoretical approaches are used to ascertain the optimal rules in affirmative incentives and cryptographically enforced limits on a certain action. In business management literature, blockchain governance is conceptualized as the processes by which individuals and groups with ongoing relationships bargain about how to adapt to changes within an institutional environment (e.g. Allen, Berg, Lane, & Potts, 2020; Daluwathumullagamage & Sims, 2020; Gruin, 2020). In this literature, the theoretical lenses of corporate governance are often utilized to analyze governance decisions. In the economics literature, and more specifically commons scholarship, blockchain governance is associated with polycentric systems operating simultaneously at many different levels of interaction, and governance decisions are perceived similar to the governance of community-pool resources (e.g. Howell, Potgieter, & Sadowski, 2019). This non-exhaustive overview of theoretical approaches to blockchain governance suggests that, first, a comprehensive conceptual framework of blockchain governance needs to accommodate various theoretical approaches in the extant literature, and second, the researchers need to reflect upon how a particular context and research focus influence policy decisions associated with blockchain governance.

3. Methodology

We conducted a systematic literature review to explore and analyze present knowledge in academic literature regarding blockchain governance. According to Gusenbauer and Haddaway (2020), only 14 of 28 academic search systems examined are well-suited to systematic reviews in that they met all necessary performance requirements for precision, recall, and reproducibility. By taking into account the disciplinary focus and the number of accessible hits, we selected ScienceDirect, Scopus, and Web of Science to run the search for research articles. In the construction of the review protocol, we followed the guidelines provided by Kitchenham and Charters (2007). The search query is constructed as follows: (Blockchain OR "block chain" OR distributed ledger) AND (governance).

The inquiry is conducted on March 19th, 2021 through the search of title, abstract, and keywords of published journal papers, book chapters, and peer-reviewed conference proceedings. We did not select a specific timeframe and included all publications published until the date of inquiry. The search result yielded respectively: Web of Science (380), Scopus (149), and ScienceDirect (72). After the removal of duplications, we constructed a consolidated list of 510 publications.[3] 15 articles were excluded additionally because of the inaccessibility to the full manuscript.

The inclusion criteria for the final sample were set as follows: (1) the publication should contain a conceptualization for blockchain governance, (2) the publication should contain a classification for blockchain governance. The selection of articles was conducted by two rounds of reviews separately by the authors. In the first round, authors categorized the publications as 'yes', 'no', 'not clear' according to the inclusion criteria.[4] Following the first round, 45 publications were marked as 'yes' for both categories, and 37 publications were marked as at least with one 'not clear'. In the second round, after a careful re-read of those 37 publications and joint consultation, a total of 67 publications were selected for the final list. The distribution of the publications in disciplinary fields[5] were as follows: Economics (12), information science/library science (12), business (10), computer science/information systems (10), engineering/electrical electronic (7), computer science/interdisciplinary application (6), law (5), management (5), computer science/theory methods (4), earth and environmental sciences (1).

To address our research questions, we followed the grounded theory approach and conducted a thematic analysis among selected articles to identify, develop, and relate the concepts in the extant literature to a conceptual framework of blockchain governance (Strauss & Corbin, 1998). The grounded theory approach follows open, axial, and selective coding processes. The first set of codes was created referring to blockchain governance and applied to the data following an iterative process of open and axial coding. The open coding phase allowed us to identify relevant concepts concerning blockchain governance, while the axial coding enabled us to connect the identified concepts to specific subcategories under blockchain governance. In selective coding, the subcategories are integrated and developed into the theory.

Through the open and axial coding, we identified three distinct categories in blockchain governance. The first category focuses on the infrastructure of the blockchain (e.g. Ertz & Boily, 2019; Ozdemir, Ar, & Erol, 2020). In those studies, blockchain governance is embedded in the technical design of blockchain infrastructure and the research focus is on elucidating how different choices by system designers about blockchain architecture, blockchain applications, and technical standards shape blockchain governance. This approach to blockchain governance is conceptualized sometimes as 'governance by blockchain' (Ølnes et al., 2017) or 'governance by infrastructure' (de Filippi & Loveluck, 2016).

The second category is about the operational processes of blockchain governance and captures the technical design choices and algorithms that affect the information exchanges, transactions, and collective actions between users (e.g. De Filippi & Loveluck, 2016; Reijers et al., 2018; Van Pelt et al., 2021). Decision-making through on-chain and off-chain methods, initiative, and consensus mechanisms are at the foci of this category. This approach to blockchain governance is conceptualized by some researchers as 'governance of blockchain' (Ølnes et al., 2017) or 'governance of infrastructure' (de Filippi & Loveluck, 2016).

In the third category, blockchain is treated as a governance technology that allows decentralized, algorithmic, and automated forms of governance to implement policy decisions (e.g. Allen et al., 2020; Yeung & Galindo, 2019). In those studies, blockchain governance focuses on the regulation, organization, and control of the blockchain-based system in a particular institutional framework. Some related governance issues

[3] 9 publications were in non-English language: 2 in Chinese, 1 in Russian, 2 in Portuguese, and 4 in Spanish. The accessible articles from non-English literature are also included in the analysis.

[4] Conceptualization: YES: a prescriptive definition of blockchain governance is provided. NOT CLEAR: not a prescriptive definition is provided, but in the text, there are references to the conceptualization of governance in the blockchain context. NO: no definition for blockchain governance is provided.Classification: YES: The article contains clear categories for blockchain governance; NOT CLEAR: the article mentions specific elements as part of blockchain governance but does not provide clear categories; NO: the article does not provide any categories for blockchain governance.

[5] We used www.semanticscholar.org and the description of publishers for categorization. A few publications are categorized in multiple disciplinary fields.

are centralized versus decentralized structures (e.g. Chen, Pereira, & Patel, 2021), rules and regulations in policy implementation (e.g. Rikken et al., 2019), and control of blockchain governance (e.g. Gruin, 2020).

In selective coding, we labeled these three categories respectively micro, *meso*, and macro level of governance. These three levels are often used in social sciences to categorize the research subjects according to the size, scale, or location. In public administration scholarship, these levels correspond mostly to the individual, organizational, and institutional levels decisions and interactions (Roberts, 2020). In a nutshell, micro-level governance refers to the choices of systems designers concerning blockchain architecture and applications. Meso-level governance refers to the group decisions and behaviors of users. Macro-level governance refers to institutional-level choices in a particular political-administrative environment.

At the data synthesis level, we distributed the selected list of articles according to the identified categories. The articles with a wider scope on governance are categorized into multiple categories. Table 1 displays the overview of the codes and subcodes retrieved from the corresponding literature and arranged according to three levels of governance.

4. Governance decisions for blockchain-based systems in the public sector

In this section, we analyze the governance decisions needed for the use of blockchain technology in the public sector. Our analysis of blockchain governance literature suggests that blockchain governance decisions in the public sector can be analyzed at micro, meso, and macro levels. In our understanding, governance decisions at one level do not stand alone, and instead, they are interrelated levels of blockchain governance. Roberts (2020) underlines that governance strategies at micro, *meso*, and macro levels are tightly knitted in public administration, and it is not possible to study one level of governance without awareness of other levels. Hence, we present in Table 2 the three levels of governance and nine types of governance decisions needed for the use of blockchain-based systems in the public sector.

In addition to these governance decisions, some studies focus on policy aims in blockchain governance (e.g. public interest, media coverage), and the macro-level exchanges across political, socio-cultural, legislative, and market-based institutions in the governance of a blockchain-based system (e.g. Hsieh et al., 2018; Meijer & Ubacht, 2018; Paech, 2017). In our framework, we do not include these elements as a separate category but presume their ubiquitous influence as contextual factors on each level of governance. For example, in the public sector, each decision about blockchain governance needs to be aligned with the policy objectives, public values, institutional framework, and societal expectations. Given this overall approach, in the following parts, we will elaborate on the governance decisions at each level in the design of a blockchain-based system in the public sector and reflect on how governance decisions at one level can affect decisions at another level.

4.1. Governance at micro level

Micro level governance concerns with the choices of system designers about the infrastructure of a blockchain-based system. The decisions concerning the infrastructure architecture of blockchain, modular applications of smart contracts and decentralized applications, and interoperability of the blockchain-based system with the existing IT infrastructure fall under this category.

4.1.1. Infrastructure architecture

Blockchains can have permissionless/permissioned and public/ private forms (Hileman & Rauchs, 2017). The difference between public and private blockchains is about who owns the data infrastructure. The difference between permissionless and permissioned systems is about the restrictions imposed on network participants in terms of read, write, and audit/commit functions. In the former, anyone can participate in the network and validate the transactions taking place in the platform, and in the latter, only selected entities are authorized to validate the transactions. These classifications are not exclusive to each other, and it is possible to have a public and private blockchain with varying degrees of permission models (see Hileman & Rauchs, 2017). For instance, the two most known blockchain platforms, Bitcoin and Ethereum, are public and permissionless blockchains. Hyperledger Fabric, R3Corda, and Quorum are some examples of technology developers that provide build-in tools for permissioned systems applicable to public and private blockchains. The merits of different types of blockchains vary technically concerning decentralization, security, scalability, speed, throughput, privacy/ confidentiality, trust, and finality dimensions. On the one hand, public and permissionless blockchains engender better trust and security for data infrastructure while experiencing a lack of scalability and performance issues. On the other hand, private and permissioned blockchains are largely developed and preferred by private enterprises (e.g. IBM, Microsoft) as they allow to a certain extent of control of the data privacy and the governance of the system.

In the public sector, the choice of blockchain calls for the consideration of several trade-off conditions concerning policy priorities (e.g. privacy, throughput, security, etc.) and effects on other levels of governance (e.g. decision-making among network actors, organization of governance). These trade-off conditions are context-dependent and should not necessarily have the same significance for all types of public sector organizations. For example, the privacy of transactions and security of data infrastructure could be the most vital factors for some public sector organizations (e.g. security and intelligence agencies), while for others, the transparency and immutability of public blockchains could be the main motivation. Similarly, higher throughput and scalability are vital concerns for enterprises, but in the public sector, often the volume of transactions and the number of users are bound to the jurisdiction area and administrative scope of the services. This network predictability may allow predetermination of the scalability and throughput needs.

Moreover, Kannengießer, Lins, Dehling, and Sunyaev (2019) identify 23 endogenous trade-off conditions among 7 DLT properties (usability, performance, flexibility, security, transparency, law & regulation, and community) that vary according to the design choice with infrastructure architecture. For example, if the purpose of the blockchain-based system is to enhance trust among users, the system architecture should prioritize transparency, which can come at the expense of other properties (e.g. usability, performance, flexibility). Although Kannengießer et al. define governance as a sub-feature of law and regulation function and focus only on the trade-offs between the governance decisions and the security of the system, it is difficult to isolate other trade-off conditions from governance decisions. Therefore, any choice in infrastructure architecture is inherently a political act and involves optimizing the trade-off conditions among various DLT properties and permissioned and permissionless systems.

4.1.2. Application architecture

As previously said, blockchain infrastructures are predisposed to particular functionalities in blockchain governance. However, these functionalities can be modified through the use of decentralized applications (DApps) and smart contracts.

DApps are open source coded digital applications or programs that exist and run on a blockchain or P2P network of computers. Through DApps, users can access blockchain networks and engage with other users for different purposes (e.g. storage of data space). Nonetheless, each DApp comes with certain advantages and disadvantages (e.g. finality, speed, scalability, energy consumption, etc.) based on their consensus and incentive mechanisms, which makes choosing a DApp inherently a governance decision. It is also possible through modular

Table 2
Three levels analysis for blockchain governance.

Level of governance	Description	Types of decisions	Issues
Micro-level	Focuses on the system designer's choices on blockchain infrastructure, modularity, and standards in building, upgrading, and adoption of the system. Unit of analysis (UoA) is at the individual level.	• Infrastructure architecture • Application architecture • Interoperability	• Permissionless/permissioned, public/private blockchains • Smart contracts and DApps • Interoperability with the existing system infrastructure
Meso-level	Focuses on the organizational processes in governing collective decision-making and actions in a blockchain network. UoA is at the organizational level.	• Decision-making mechanism • Incentive mechanism • Consensus mechanism	• On-chain/off-chain decisions • Types of (dis)incentives • PoW, PoS, DPoS, PoA,etc.
Macro-level	Focuses on the institutional rules and norms that derive from the respective constitutional, cultural, historical, and legal foundations. UoA is at the institutional level	• Organization of governance • Accountability of governance • Control of governance	• Role distribution in governance • Regulation and enforcement of rules • Human controlled vs automated agents

DApps to anchor values in a non-blockchain system or a private blockchain to a public blockchain. For instance, the land registry use case in Sweden employs a two-layered blockchain approach, where the summary of hashes from a private blockchain is stored in Bitcoin blockchain (Kairos Future, 2017). Therefore, it is possible to circumvent certain trade-offs between DLT properties (e.g. performance vs security) through the use of DApps.

Smart contracts are mechanisms that contain digital assets of two or more involved parties, where assets are distributed automatically according to predefined response actions when trigger conditions are met (Governatori et al., 2018) DApps accesses the blockchain network through smart contracts, which enforce the term of the agreement between two parties. Through the combination of smart contracts and DApps, it is possible to create decentralized autonomous organizations (DAO) where the operational rules are encoded on blockchain in the form of smart contracts, and DAOs can autonomously or semi-autonomously operate without centralized control or third-party intervention (Wang et al., 2019). These new forms of organizations can redefine the mechanisms of control and coordination in public management. For example, units specialized in streamlining, regulatory, and network governance can be replaced by DAOs. Furthermore, new forms of managerial arrangements with non-governmental organizations can be established as DAO to replace traditional forms of public-private partnerships and collaborative governance mechanisms.

4.1.3. Interoperability

European Interoperability Framework (EIF) states that interoperability governance in the public sector requires an integrated governance approach across legal, technical, semantic, and technical interoperability.[6] In the same vein, with blockchain interoperability, we refer to the ability of a blockchain network to share, see, and access information across existing data management systems in the public and private domain without the need for an intermediary to do the exchange. In that sense, an important decision concerning interoperability is assessing to what extent blockchain governance complies with the existing mechanisms, technologies, regulations, and standards in the digital governance landscape. There are three types of challenges, we can identify concerning the interoperability of blockchain. First, the lack of standardization from technical protocols to smart contracts that connect auxiliary technologies such as AI and automated agencies in blockchain platforms (Janssen et al., 2020). Moreover, for the moment, stored information on blockchains is not necessarily in line with market standards and practices such as ISDA (International Swaps and Derivatives Association), FPL (FIX Protocol Ltd), or ISO (International Organization for Standardization) (Janssen et al., 2020). Secondly, blockchains are by design are not interoperable with each other (Lafourcade & Lombard-Platet, 2020). Several solutions have been proposed to facilitate cross-chain transactions such as facilitating messaging via a management chain, using cross-chain cryptocurrency for atomic asset transfers, or direct communication via hardware connections using TLS or smart contracts, each with its unique set of problems to solve (Johnson, Robinson, & Brainard, 2019). Thirdly, interoperability challenges can arise from the specific needs in the public service domain. For example, Zhang, White, Schmidt, and Lenz (2017) identify particular interoperability challenges in the healthcare sector concerning the evolvability, flexibility, extent, and continuity of data exchange across various data providers.

Interoperability challenges can affect blockchain governance choices in two possible ways. Firstly, they can preclude the scalability of blockchain-based solutions and thereby limit the use of blockchain only to specific functions (e.g. data verification through verifiable credentials). The lack of scalability can further undermine the applicability of decentralized and permissionless systems. Secondly, the technology choices of stakeholder organizations in a blockchain ecosystem can elevate one blockchain infrastructure and associated governance choices over others and establish it de facto as the system architecture choice in the public sector. Especially, national and international policy initiatives can be a trendsetter in that regard. For example, Estonia aims to solve the interoperability challenges by creating one standardized system in public services based on keyless signature infrastructure (KSI). KSI does not rely on the joint actions of the users to verify the data, and unlike proof of work (PoW) or proof of stake (PoS) consensus mechanisms, uses timestamping to verify the integrity of the data.[7] Another example is the European Blockchain Service Infrastructure[8] (EBSI) which aims to provide cross-border public services in the EU by utilizing blockchain. As part of the EBSI, member states are expected to establish the necessary infrastructure for the transition and to assign nodes (i.e. trusted and capable entities in every member state) to support the proof-of-authority (PoA) consensus mechanism. In case there is a nationwide data-sharing platform (e.g. digital solutions in the Estonian government) or if a European or global level blockchain platform (e.g. EBSI) is adopted, the interoperability requirements may delimit available governance choices at the micro level. One other interoperability consideration is the extent that blockchain can incorporate big data and IoT solutions. The digital transformation in the public sector has introduced several technologies,

[6] For details of EIF, please see ISA[2] program at https://ec.europa.eu/isa2/eif_en

[7] It is debatable to call KSI technology blockchain, but the government of Estonia prefers to call it blockchain. For the description, see https://e-estonia.com/solutions/security-and-safety/ksi-blockchain/

[8] see https://ec.europa.eu/digital-single-market/en/blockchain-technologies

and blockchain as a general-purpose technology has a higher chance of success if it complements the existing technologies rather than replaces them.

4.2. Governance at meso level

Meso level governance concerns with the interactions among the network community on which the blockchain-based system rests upon. A blockchain-based system relies on the interactions among different types of users such as miners, verifiers (or node operators), core developers, token holders, content producers, and network users. Governance decisions at the meso level set up how decision-making among these actors is managed, what type of incentive mechanisms support system maintenance, and how consensus mechanisms affect the role of actors in blockchain governance.

4.2.1. Decision-making mechanism

The decision-making mechanism varies between on-chain and off-chain governance processes (Reijers et al., 2018). In on-chain governance, stakeholders participate in discussions and decisions through the protocol itself, and when a decision is reached through a voting procedure or surpassing a threshold user number, the protocol adapts automatically the decision. In on-chain governance, the way that the engagement and decision-making take place is encoded directly in the underlying infrastructure. For example, during the introduction of soft-fork activation protocols to Bitcoin (i.e. BIP 8 or BIP 9), miners used on-chain means to signal their support to the proposed upgrade. When 95% of blocks signaled support for the upgrade, the changes are enforced automatically after a short period of time. The strength of on-chain governance is its enforcement mechanism, when a decision is agreed upon it is implemented by following the rules embedded in the code. However, the downside of this mechanism is that it automates a winner-takes-all rule. The winning majority determines all system functioning, and as such, it risks alienating political dissidents from the process. In political sciences, this is called majoritarian democracy, which is often criticized as being undemocratic or as a lesser form of democracy.

Off-chain governance refers to the endogenous and exogenous rules and processes of deliberations around the protocol that contribute to the operations and development of blockchain-based systems (Reijers et al., 2018). For example, Bitcoin developers share their improvement proposals (BIPs) through a mailing list and Ethereum collects improvement proposals (EIPs) on Github (Ehrsam, 2017). The miners can decide whether to adopt the improvement proposals in practice. Although off-chain governance presents a more democratic alternative and allows an incremental adaptation, it preserves an inherent security risk in permissionless systems. The miners of the system are rent-seekers and they do not necessarily preserve the technical expertise to evaluate a proposal. Therefore, an initially benign-looking software modification initiated by a malicious actor can create security risks in the future (Finck, 2018).

Both governance processes infer trade-offs for system designers and policymakers. On-chain governance brings the trade-off between efficient decision-making and transition processes whilst risking destabilization due to political dissonance. Off-chain governance brings the trade-off between enhancing the political consensus in the decision-making and transition processes whilst making the system security vulnerable to the rent-seeking behavior of the miners. It is also possible to develop hybrid systems, where some decisions can be taken through on-chain processes, whereas others can be through off-chain processes.

Additionally, depending on the blockchain protocol, some actors may hold veto rights over certain decisions, or some decisions can be open only to certain actors to vote in. Here the institutional framework, area of application, and country-specific conditions may dictate different actors to take a more prominent role in the on-chain and off-chain governance processes. Since a core added value of blockchain is to establish confidence in processes where there is a lack of it, the decision-making mechanisms may need to prioritize the involvement of the relevant actors and increase the level of transparency in the design and operation of blockchain applications. For that, a social layer can be introduced in blockchain governance, where core developers, stakeholders, and societal actors deliberate on the political and functional implications of the system design choices. The deliberations that take place at the social layer can foster on-chain processes to create a politically legitimate process and can serve as a dynamic constitution of the blockchain-based system. The challenge is establishing an inclusive decision-making mechanism that creates legitimacy in blockchain governance without deadlocking the system (e.g. Bitcoin block size debate). A democratic constitution of blockchain governance may be needed to establish the rules and roles of the verifiers, developers, and users of the system.

4.2.2. Incentive mechanism

In the Bitcoin whitepaper, Nakamoto (2008) introduced an incentive mechanism to ensure the continuous engagement of Bitcoin users in network maintenance. Both in Bitcoin and Ethereum blockchains, this mechanism relies on monetary rewards in the form of blockchain cryptocurrency, which aligns the individual rent-seeking behavior with the overall benefit of the platform. For public sector organizations, using monetary incentives for user engagement might create ethical and political challenges, however, not all incentive mechanisms need to leverage the monetary value of cryptocurrencies. For example, allocations of tokens and reputation scores that grant the users enhanced access to platform functions and weighted voting rights in decision-making processes can be some non-monetized rewards.

Not only the methods of incentivizing but also the way that consensus protocols incentivize the miners and verifiers can have drastic implications for the overall blockchain governance. For instance, the PoW mechanism of Bitcoin alongside with monetary incentive mechanism has paved the way to the consolidation of mining. Consequently, big mining pools have emerged across the globe and specialized hardware among miners has become widespread. Currently, it is estimated that four big mining pools at the Bitcoin network and two mining pools at the Ethereum network control over 50% of transactions (De Filippi and Wright 2018, 40). This consolidation of power undermines the distributed and decentralized features of blockchain networks- even for the big ones such as Bitcoin and Ethereum, and risks the legitimacy and trust invested in on-chain governance mechanisms.

Another related governance decision is about the disincentivizing effect of transaction fees. Transaction fees are the cost of actions in a particular blockchain such as transactions or executions of smart contracts (e.g. 'gas' in Ethereum). The disincentivizing effect of transaction fees and the incentivizing effect of rewards to miners, create the conditions of trade-offs and rational choice calculations for the users and miners to engage with blockchain. In case, the cost outweighs the anticipated benefits of engagement, some blockchain applications can lose their attractiveness or miners might find less value to support the blockchain altogether, adversely affecting the security of the blockchain (De Filippi and Wright 2018, 41).

4.2.3. Consensus mechanism

A consensus mechanism is at the core of blockchain-based systems to coordinate the decentralized actions of users in deciding which information can be added to the blockchain. Different consensus mechanisms exist, but most blockchains either rely on Nakamoto consensus (or PoW) that ties mining capability to computing power or Byzantine consensus that uses staking to assign miners, such as proof-of-stake (PoS) and delegated proof-of-stake (DPoS). There are also proof-of-authority (PoA) systems, where a lower number of nodes or masternodes take the role of transaction validators. Each of these consensus mechanisms has advantages and disadvantages over others, and their affinity toward decentralized or centralized governance structures varies.

PoW is mostly used in permissionless, public blockchains, such as

Bitcoin and Ethereum,[9] where the users validate the transactions by solving complex mathematical puzzles through the computing power of the hardware. The advantage of the PoW system is its stability to deter cyberattacks (e.g. denial-of-service-attacks) while maintaining a distributed system governance. However, its vulnerability toward 51% attack, high energy cost, increasing centralization of mining operations, and low transaction throughput are some of the significant challenges for PoW-based systems. Especially, increased strain on the environment imposed by the high energy demand of PoW-based systems reduces their likelihood of preference for public sector projects.[10]

In PoS, the mining power is attributed to nodes in the proportion of tokens (or coins) held by nodes instead of their computing powers. Node operators lock away a stake for the right to participate in block creation, and nodes with bigger stakes have higher chances to be selected to verify transactions. A transaction fee is paid to the node operator in return for the transaction verification. In the case of fraudulent transactions or any misbehavior, the node loses the right to participate in staking. The difference in DPoS is that the token holders choose a small number of nodes as delegates by staking tokens with different candidates. If the delegate is chosen for block creation, a fraction of the reward is allocated to those who voted for the delegate. In some systems, decision-making power is associated with the delegation of tokens where delegates may have the capability to monitor and amend network parameters such as fees, block size, block rewards, and the length of the transaction cycle (Karjalainen 2020). The advantage of PoS is that it is less susceptible to 51% attacks and more scalable with higher transaction throughput, but it is assumed as less secure than completely decentralized PoW systems (EdChain, 2018).

In PoA systems, unlike the PoS and PoW systems, the identity of the validator is known, and the assumption is that the reputation of the validator plays the role of stake. The advantage of PoA systems is that they can achieve much higher throughput as a result of the lower number of validators and they are suited for both private networks and public networks. However, the downside is that PoA is not imbued with the sense of security derived from decentralized consensus mechanisms, and the nodes, therefore, need to be kept uncompromised. Hence algorithmic trust typical of Bitcoin or Ethereum is not present in a PoA-based blockchain rather an ex-ante trust is required in node selection (also see Table 2). For instance, as a PoA-based blockchain, the nodes in EBSI are selected from key public or private institutions that had already preserved a central role in digital governance (e.g. BELNET and SMALS in Belgium).

The differences among consensus mechanisms also affect the role of users in blockchain governance and overall public governance. For instance, PoW or PoS as a mechanism empowers the role of the users and miners as *demos* and makes them indispensable for the continuity, safety, and relevance of the system. In both of these mechanisms, the users are co-producers of blockchain governance. In the PoA, the users are the beneficiaries of the system whereas some organizations hold the roles of a public agency for the production of public services. In public governance literature, this distinction is associated with the beneficiary or client role of citizens in traditional public administration and new public management regimes, and the co-producer role of citizens in new public governance systems (Osborne and Strokosch, 2010).

4.3. Governance at macro-level

Macro-level governance focuses on how rules and norms that derive from the constitutional, cultural, historical, and legal foundations of that institution affect the organization, accountability, and control of the blockchain-based system in realizing policy goals and functions. Macro-level governance choices serve as "embedded traits" that act as parameters on both individual and organizational decision-making (Williamson, 1993). More specifically, how the decision-making rights are distributed across network actors, what type of accountability mechanisms are in place, and who controls and oversees the implementation processes fall under the scope of macro-level governance decisions.

4.3.1. Organization of governance

The choices about the organization concern with the distribution of roles in governance decisions within the blockchain network. Here, we identify four different approaches, namely, centralized, semi-centralized (or hybrid), polycentric, and decentralized forms of governance. Centralized governance refers to those where a specific group of people or organizations make the governance decisions, and the decision-making processes can be organized through off-chain or on-chain processes. A semi-centralized or hybrid governance is when some governance decisions (e.g. conflict resolution) are taken only by a centralized board of directors, and some other governance decisions (e.g. concerning the network of users or platform functions) can be taken with an additional on-chain voting procedure by the platform users. Here, the impact of the users' vote can vary on the actual implementation of decisions. For example, an absolute or qualified majority in a caucus of users can be required, or different weighting options can be used for the result of voting processes to supplement decisions taken by the board of directors.

In polycentric governance, different clusters of actors (e.g. miners, developers, nodes) hold different roles and responsibilities in blockchain governance, and governance necessitates taking into account what the others are doing (Stephan et al. 2019). In a decentralized structure, governance processes are not dominated by a single actor or a group of actors, rather the decisions are taken by the majority of users operating in the blockchain network either through on-chain voting processes or coordinated mining action. Here the choice architecture of voting processes and the openness of propositions to the public may influence the decentralized nature of the governance structure. Furthermore, in open-source decentralized systems, improvement proposals and DApps can be introduced directly by network users without the interference of an intermediary actor (e.g. developers).

It is important to underline that certain organizational structures may have different affinities for particular governance choices at micro or *meso* levels. For example, while centralized governance might be more suitable for permissioned blockchain-based systems, polycentric or decentralized governance may be more suitable for permissionless systems. Or, while PoA may be more suitable to semi-centralized systems, PoS and PoW may be more suitable to polycentric or decentralized systems. It is also possible that the power relations of actors may alter an initially different-looking governance structure into another. For example, if on-chain governance processes in PoW or PoS-based systems are dominated by a few large operators who control most of the mining resources and/or token holdings, an initial decentralized governance structure may act as a semi-centralized or polycentric governance structure. Or, if off-chain governance processes are dominated by a few specialized influential players, a centralized governance structure may act like a semi-centralized or polycentric structure.

4.3.2. Accountability of governance

Accountability is about how rules in governance (e.g. dispute resolution, change management) are regulated and enforced. Following Treib et al.'s typology (2007), four forms of accountability mechanisms can be identified in blockchain governance: coercion, voluntarism, targeting, and framework regulation. These four types are distinguished along two dimensions: the type of instruments applied (legally binding legislation or soft law) and the approach to enforcement (flexible or rigid).

[9] In 2020, Ethereum launched a series of upgrades called Ethereum 2.0, which includes a transition to PoS.

[10] For example, during the initial design process of EBSI, the European Commission announced its intention to avoid PoW for the anticipated system (European Blockchain Partnership 2019).

Coercion is characterized by binding regulative instruments prescribing detailed and fixed standards in the implementation. In the blockchain context, coercion can be captured by the concept of *lex cryptographica* (de Filippi & Wright, 2018). *Lex cryptographica* means that the rules of exchanges are inbuilt codes, and as such code becomes the law in blockchain governance. Through the use of smart contracts, rewards and sanctions are executed automatically creating a deterministic system of governance. The challenge with transposing law into code is that codes are written ex-ante, in strict and formalized language, and therefore, code-based rules need to be predictable and leave no room for interpretation (de Filippi & Wright, 2018). This inherently limits the applicability of code-based rules in areas where the contingencies and conditionalities cannot be determined a priori.

Voluntarism is based on legally non-binding instruments and defines broad goals in implementation. In the blockchain context, this mode of governance is captured by soft forks. A soft fork does not change the structure of blockchain, but it modifies the functions of blockchain. The implementation of a soft fork relies on the coordinative action of the majority of users to implement the suggested changes. The changes enter into force only if the majority of the network's mining power adopts them. Otherwise, the soft fork fails, and the old chain remains unchanged. In the case of political dissonance among different groups of users in a blockchain network, a soft fork presents a flexible instrument to modify the system. For example, when no political consensus was achieved among the blockchain community to change the Bitcoin block size (i.e. the 1-megabyte rule), a segregated witness through a user-activated soft fork was used. Given the consensus rules of Bitcoin are controlled by the economic majority, the economic majority was able to activate segregated witness on their own, bypassing the blocking miners.

Targeting uses non-binding recommendations but unlike voluntarism, it relies on detailed descriptions for regulations. In the blockchain context, targeting practices are often used for the introduction of improvement proposals and DApps in a blockchain network. Through improvement proposals (e.g. BIPs), anyone can suggest software changes, which are subsequently evaluated and debated by the network community. If the proposal reaches community consensus, it is considered final. In the implementation of improvement proposals, users exercise agency in deciding whether to install new software or not.

Finally, framework regulation creates binding rules for users but unlike coercion, users have freedom of choice whether to accept the policy options or not. This accountability mechanism in the blockchain context is best captured by hard forks. A hard fork occurs when a rule change is adopted in blockchain protocol and the nodes of the newest version of a blockchain no longer accept the older version of the blockchain. In the case of a hard fork, all nodes are meant to work by the new rules to upgrade their software. Otherwise, a permanent split from the previous version of the blockchain occurs and two different blockchains are created. A famous case of hard fork occurred in the Ethereum blockchain following the DAO hack in 2016, where $50 million worth of funds held by the platform was hijacked by exploiting a bug in the system (Finck, 2018). Following the hack, a philosophical debate broke out in the community about the right course of action. The non-intervention faction argued that changing the code would undermine the immutability of the code and thereby the 'code is law' notion of the governance system. The others argued rewriting the transaction history by creating a hard fork in the system to reduce the likelihood of judicial action. Eventually, a hard fork was accepted by the majority of the miners, creating effectively a new chain based on the older version of the transaction history before the hack occurred (Finck, 2018). Yet, the split resulted in the creation of two blockchains, namely Ethereum Classic and Ethereum.

4.3.3. Control of governance

The control of governance is about what type of control mechanisms are placed in the implementation of governance decisions and to what extent the governance decisions are automated. Control mechanisms can pertain to systemic changes (e.g. hard and soft forks), rules of operations, or system functions (e.g. DApps). Especially, automation of governance decisions and processes in blockchain governance is an important issue in the public sector. Based on the theoretical and empirical cases, we identify three possible forms of automation in blockchain governance: fettered governance, semi-autonomous governance, and automated governance.

In fettered governance, human agents hold all decision rights, and the decisions are implemented by the consent and collaborative actions of actors. Currently, most of the blockchain platforms operate on fettered governance, where the operations (e.g. verification, order of transactions, voting, etc.) are controlled by humans, be it centralized or decentralized.

In semi-autonomous governance, we expect automated agents to supply certain governance functions. Here the access to off-chain data through oracles,[11] and convergence of platform functions with other digital technologies such as AI and IoT can supplement the role of automated agents. For instance, through the injection of AI technologies in blockchain networks, it is possible to improve the capacities of smart contract management and to introduce more efficient mining processes to reduce energy consumption (Hassani, Huang, & Silva, 2018). A case in point is QTUM blockchain, where in the case of problematic gas prices for certain operations (e.g. higher prices for processing blocks than creating them), smart contracts can temporarily increase the gas prices for the problematic operations to mitigate malign attacks on the network. These so-called decentralized governance protocols (DGP) provide an alternative to hard and soft forks for hotfixes without disrupting the user experience (Bosankic, 2018).

In automated governance, new digital technologies and advanced data analytics techniques supplemented by exogenous data sources can create complex automated governance mechanisms. Here, we expect the human agency to be in a more beneficiary position while networks of machines and complex algorithms regulate transactions according to the changing environmental conditions. For example, the terra0 project in the Netherlands aims to create self-governing ecosystems for the management of publicly owned natural resources such as forests by utilizing remote sensing, AI, token and blockchain technologies.[12] The project envisions a DAO, where the satellite imagery through smart contracts designates the trees that can be harvested before damaging the forest too much, and that automatically trades licenses to cut the trees to vendees. The generated income is used to purchase shares of land from the actual landowners in the form of tokens, creating a non-human owned property capable of utilizing its own economic unit.

A decision toward the removal of the human element is closely linked with the embedded public values in public sector organizations and the sectoral area of application. The salience of efficiency and cost-effectiveness principles may insinuate the replacement of certain functions and organizations in public services with non-human controlled DAOs or automated agents. Yet again, replacing a large number of public sector organizations and administrative positions with automated agents may be politically unfeasible. One downside of non-human controlled DAOs is that the notion of accountability can be blurred in public management. Here, the cultural and behavioral reservations may suggest certain roles and decisions that can be automated to be left in the hands of actual people. Furthermore, the adaptation of automated solutions needs to comply with the existing capacities and practices at the societal level concerning digital governance. A core consideration here is assessing to what extent people can manage their digital identities and assets and whether they need custodian organizations in public governance.

[11] Oracles are third-party services that bridge external information in a blockchain network

[12] For details, see https://terra0.org/

5. Conclusion

In this article, we addressed what governance decisions are needed to design a blockchain-based system in the public sector, and how contextual factors in the public sector shape available choices in blockchain governance. To answer these questions, we have reviewed the conceptualization of blockchain governance in different disciplines and developed a novel conceptual framework to analyze blockchain governance in the public sector. Our categorization of blockchain governance was stemmed from a systematic literature review and we used public management concepts and theories in elucidating the governance choices in the design of blockchain-based systems. Our framework suggests that blockchain governance in the public sector entails design decisions concerning the infrastructure architecture, application architecture, interoperability, decision-making mechanism, incentive mechanism, consensus mechanism, organization, accountability, and control of governance.

We render the contribution of this article to the literature in two ways. First, despite the widespread interest in the use of blockchain in the public sector, and the challenges concerning governance, in particular, the academic production in the field of public administration about the topic has been conspicuously missing. We aimed to address this gap and to our knowledge, this article is the first of its kind which investigates how blockchain-based systems can be governed in the light of the knowledge base in public administration literature.

Secondly, the conceptualization of governance in blockchain literature is fragmented and we found that a more cohesive framework is needed to systematically analyze the implications of governance decisions in the design of blockchain-based systems. By demonstrating the policy implications of governance choices from micro to macro level, we have sought to provide a primer for researchers and practitioners on blockchain governance. In this article, we applied this framework into the public sector context, but we presume, nonetheless, the applicability of the framework in other sectoral areas as well.

There are several key takeaways from our analysis for the system designers and decision-makers interested in applying blockchain-based solutions in public management. First, policymakers and system designers need to reflect upon the interlinkages between the levels of governance and assess the implications of choices at one level to other levels of governance. For instance, a possible policy aim of building trust in policymaking may require a more decentralized form of governance that can in return influence the choices at micro and *meso* level of governance. Our model does not predicate a hierarchy of importance among different levels of governance nor prioritize a governance decision over others. Furthermore, our model does not assume a particular sequence in assessing the implications of governance decisions for policymaking (e.g. going from micro-level to macro-level governance). Our model provides a systematic tool to assess the governance implications of policy choices and preferences of decision-makers in a holistic manner. We expect the importance and the necessity of certain governance decisions to vary according to the context and the sectoral area of application.

Secondly, legislative, market, political-administrative, and socio-technological framework conditions in particular sectoral areas (e.g. health, security, education) may accentuate certain choices in blockchain governance. The neoinstitutionalist theories suggest that cost-benefit calculations (e.g. financial cost, transaction cost, political cost, etc.), norms and values (e.g. legitimacy of actors, preservation of autonomy, transparency, and accountability, etc.), and path dependency concerning technological infrastructure (e.g. crossroad databases in Belgium, KSI in Estonia) are some ways whereby institutional factors may play a determinant role on governance choices. The existence or absence of a regulative framework concerning data privacy (e.g. GDPR, healthcare data regulations), token technology, smart contracts, DAOs, and AI are other key institutional factors that can influence governance decisions.

Thirdly, blockchain governance is innately not agnostic nor apolitical. Design choices made by system designers at the micro level or the power dynamics across the blockchain network make accentuate certain governance choices over others. Furthermore, the use of blockchain technology in the public sector likely requires the government and public sector organizations to give up certain prerogatives in public management. To what extent the government needs to give up its prerogatives through blockchain technology is associated with the level of trust vested in the public sector organizations and society. Permissionless-public blockchains are expected to be desirable in public service areas where there is a low level of trust among users (Meijer & Ubacht, 2018). However, the literature on trust suggests that when there is a low level of trust in society or other stakeholders, decision-makers are more disposed to keep the control through direct or indirect means (Bijlsma-Frankema & Costa, 2005). Therefore, we strongly recommend further research on elucidating the relationship between the trust in the public sector and the choices of policymakers toward more decentralized and automated governance designs in blockchain-based systems.

Recently, there is a growing interest in the governance of blockchain-based systems spearheaded by computer sciences, economics, and law, but the literature is still in its infancy. For the systematic literature review, we selected only the high-quality publications, but the repetition of the analysis including the grey literature and technical reports can provide a wider pool of samples and thus further insight on the approaches to blockchain governance. Moreover, there is a need for more empirical research on the subject as well as combining the research in computer sciences with administrative and social sciences to further this debate. Given the multi-faceted and across-the-disciplines nature of the governance challenges, it is particularly complex for public sector organizations to decide on 'when blockchain is an appropriate technology in public management?' and 'how blockchain-based public services can be governed?'. An interdisciplinary, holistic approach to these questions is essential, as the future of blockchain technology in the public sector depends on the syntheses of technological, political, societal, managerial, and legal solutions. Therefore, it is critically timely and societally relevant to research how and to what extent blockchain technology can transform the public sector.

Funding

This research is funded by the KU Leuven Internal Research Funds.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Alketbi, A., Nasir, Q., & Abu Talib, M. (2020). Novel blockchain reference model for government services: Dubai government case study. *International Journal of Systems Assurance Engineering and Management, 11*(6), 1170–1191. https://doi.org/10.1007/s13198-020-00971-2.

Allen, D. W. E., & Berg, C. (2020). Blockchain governance: What we can learn from the economics of corporate governance. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3519564.

Allen, D. W. E., Berg, C., Lane, A. M., & Potts, J. (2020). Cryptodemocracy and its institutional possibilities. *The Review of Austrian Economics, 33*(3), 363–374. https://doi.org/10.1007/s11138-018-0423-6.

Allessie, D., Janssen, M., Ubacht, J., Cunningham, S., & van der Harst, G. (2019). The consequences of blockchain architectures for the governance of public services: A case study of the movement of excise goods under duty exemptions. *Information Polity, 24*(4), 487–499. https://doi.org/10.3233/ip-190151.

Angarita, R., Dejous, A., & Blake, P. (2019). From centralized to decentralized blockchain-based product registration systems: The use case of lighting and appliances. In *INFOCOM 2019 - IEEE conference on computer communications workshops, INFOCOM WKSHPS 2019* (pp. 650–655). https://doi.org/10.1109/INFCOMW.2019.8845267.

Arisi, M., & Guarda, P. (2020). Blockchain and eHealth: Seeking compliance with the general data protection regulation BioLaw journal-Rivista di BioDiritto. *BioLaw Journal - Rivista Di BioDiritto, 21*(2), 477–496. https://bitcoin.org/bitcoin.pdf.

Atzori, M. (2017). Blockchain technology and decentralized governance: Is the state still necessary? Journal of Governance and Regulation, *6*(1), 45–62. Doi:10.22495/jgr_v6_i1_p5.

Bagloee, S. A., Heshmati, M., Dia, H., Ghaderi, H., Pettit, C., & Asadi, M. (2021). Blockchain: The operating system of smart cities. *Cities, 112*. https://doi.org/10.1016/j.cities.2021.103104.

Beck, R., Müller-Bloch, C., & King, J. L. (2018). Governance in the blockchain economy: A framework and research agenda. Journal of the Association for Information Systems, 19(10), 1020–1034. Doi:10.17705/1jais.00518.

Benedict, G. (2019). Challenges of DLT-enabled ScalableGovernance and the role of standards. Journal of ICT Standardization, 7(3), 195–208. Doi:10.13052/jicts2245-800X.731.

Bertolami, O., & Francisco, F. (2021). A digital contract for restoration of the earth system mediated by a planetary boundary exchange unit. *Anthropocene Review.*. https://doi.org/10.1177/2053019620987270.

Bijlsma-Frankema, K., & Costa, A. C. (2005). Understanding the trust-control nexus. *International Sociology, 20*(3). https://doi.org/10.1177/0268580905055477.

Bosankic, L. (2018). Blockchain governance: Takeaways from nine projects. Medium https://medium.com/@leo_pold_b/blockchain-governance-takeaways-from-nine-projects-8a80ad214d15.

Brinkmann, M., & Heine, M. (2019). Can blockchain leverage for new public governance? A conceptual analysis on process level. In *ACM international conference proceeding series, part F148155* (pp. 338–341). https://doi.org/10.1145/3326365.3326409.

Carvalho, A., Merhout, J. W., Kadiyala, Y., & Bentley, J. (2021). When good blocks go bad: Managing unwanted blockchain data. *International Journal of Information Management, 57*, 102263. https://doi.org/10.1016/j.ijinfomgt.2020.102263.

Chen, Y., Pereira, I., & Patel, P. C. (2021). Decentralized governance of digital platforms. *Journal of Management, 47*(5), 1305–1337. https://doi.org/10.1177/0149206320916755.

Daluwathumullagamage, D. J., & Sims, A. (2020). Blockchain-enabled corporate governance and regulation. *International Journal of Financial Studies, 8*(2), 1–41. https://doi.org/10.3390/ijfs8020036.

Dimitropoulos, G. (2020). The law of blockchain. *Washington Law Review, 95*(3), 1117–1192. https://doi.org/10.2139/ssrn.3559970.

Diniz, E. H., Cernev, A. K., Rodrigues, D. A., & Daneluzzi, F. (2020). Solidarity cryptocurrencies as digital community platforms. *Information Technology for Development*. https://doi.org/10.1080/02681102.2020.1827365.

Dirose, S., & Mansouri, M. (2018). Comparison and analysis of governance mechanisms employed by blockchain-based distributed autonomous organizations. In *2018 13th system of systems engineering conference, SoSE 2018* (pp. 195–202). https://doi.org/10.1109/SYSOSE.2018.8428782.

Dobler, M., Ballandies, M., & Holzwarth, V. (2019). On the extension of digital ecosystems for SCM and customs with distributed ledger technologies: Requirements Anlysis, innovation assessment, and prototype Design for the Lake Constance Region. In *Proceedings - 2019 IEEE international conference on engineering, technology and innovation, ICE/ITMC 2019*. https://doi.org/10.1109/ICE.2019.8792646. June 1.

Dursun, T., & Üstündağ, B. B. (2021). A novel framework for policy based on-chain governance of blockchain networks. *Information Processing and Management, 58*(4), 102556. https://doi.org/10.1016/j.ipm.2021.102556.

EdChain. (2018). POW vs. PoS. *A Comparison of Two Blockchain Consensus Algorithms. Medium. PoS*.

Ehrsam, F. (2017). Blockchain governance: Programming our Future. Medium https://medium.com/@FEhrsam/blockchain-governance-programming-our-future-c3bfe30f2d74.

Erbguth, J., & Morin, J. H. (2019). Towards governance and dispute resolution for DLT and smart contracts. In *Proceedings of the IEEE international conference on software engineering and service sciences, ICSESS, 2018-November* (pp. 46–55). https://doi.org/10.1109/ICSESS.2018.8663721.

Ertz, M., & Boily, É. (2019). The rise of the digital economy: Thoughts on blockchain technology and cryptocurrencies for the collaborative economy. *International Journal of Innovation Studies, 3*(4), 84–93. https://doi.org/10.1016/j.ijis.2019.12.002.

de Filippi, P., & Loveluck, B. (2016). The invisible politics of bitcoin: Governance crisis of a decentralised infrastructure. Internet Policy Review, 5(3). Doi:10.14763/2016.3.427.

de Filippi, P., Mannan, M., & Reijers, W. (2020). Blockchain as a confidence machine: The problem of trust & challenges of governance. *Technology in Society, 62*, 101284. https://doi.org/10.1016/j.techsoc.2020.101284.

de Filippi, P., & Wright, A. (2018). *Blockchain and the law: The rule of code*. Harvard University Press.

Finck, M. (2018). *Blockchain regulation and governance in Europe* (In Cambridge University Press).

Flood, J., & McCullagh, A. (2020). Blockchain's future: Can the decentralized blockchain community succeed in creating standards? *Knowledge Engineering Review, 35*. https://doi.org/10.1017/S0269888920000016.

Franke, L., Schletz, M., & Salomo, S. (2020). Designing a Blockchain model for the Paris Agreement's carbon market mechanism. *MDPI, Open Access Journal, 12*(3), 1–20. https://ideas.repec.org/a/gam/jsusta/v12y2020i3p1068-d315825.html.

Franks, P. C. (2020). Implications of blockchain distributed ledger technology for records management and information governance programs. *Records Management Journal, 30*(3), 287–299. https://doi.org/10.1108/RMJ-08-2019-0047.

Governatori, G., Idelberger, F., Milosevic, Z., Riveret, R., Sartor, G., & Xu, X. (2018). On legal contracts, imperative and declarative smart contracts, and blockchain systems. *Artificial Intelligence and Law, 26*(4), 377–409. https://doi.org/10.1007/s10506-018-9223-3.

Gruin, J. (2020). The epistemic evolution of market authority: Big data, blockchain and China's neostatist challenge to neoliberalism. *Competition and Change*. https://doi.org/10.1177/1024529420965524.

Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google scholar, PubMed, and 26 other resources. *Research Synthesis Methods, 11*(2), 181–217. https://doi.org/10.1002/jrsm.1378.

Halaburda, H., & Mueller-Bloch, C. (2020). Toward a multidimensional conceptualization of decentralization in Blockchain governance: Commentary on "two sides of the same coin? Decentralized versus proprietary Blockchains and the performance of digital currencies" by Cennamo, Marchesi, and Meyer. *Academy of Management Discoveries, 6*(4), 712–714. https://doi.org/10.5465/amd.2020.0134.

Hassani, H., Huang, X., & Silva, E. (2018). Big-crypto: Big data. *Blockchain and Cryptocurrency., 2*, 34. https://doi.org/10.3390/bdcc2040034.

Hermstrüwer, Y. (2019). Democratic Blockchain design. *Journal of Institutional and Theoretical Economics JITE, 175*(1), 163–177. https://doi.org/10.1628/jite-2019-0023.

Hileman, G., & Rauchs, M. (2017). *2017 global blockchain benchmarking study*. Available at SSRN 3040224.

Howell, B. E., Potgieter, P. H., & Sadowski, B. M. (2019). Governance of Blockchain and distributed ledger technology projects. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3365519.

Hsieh, Y.-Y., Vergne, J.-P., & Wang, S. (2018). The internal and external governance of blockchain-basedorganizations. In *Bitcoin and beyond (pp. 48–68)*. Routledge. https://doi.org/10.4324/9781315211909-3.

Janssen, M., Weerakkody, V., Ismagilova, E., Sivarajah, U., & Irani, Z. (2020). A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors. *International Journal of Information Management, 50*, 302–309. https://doi.org/10.1016/j.ijinfomgt.2019.08.012.

Jia, K., & Zhang, F. (2018). Between liberalization and prohibition. In *Bitcoin and beyond (pp. 88–108)*. Routledge. https://doi.org/10.4324/9781315211909-5.

John, T., & Pam, M. (2018). Complex adaptive blockchain governance. *MATEC Web of Conferences, 223*. https://doi.org/10.1051/matecconf/201822301010.

Johnson, S., Robinson, P., & Brainard, J. (2019). Sidechains and interoperability. *ArXiv*. http://arxiv.org/abs/1903.04077.

Kaal, W. A. (2020). Decentralized corporate governance via blockchain technology. In *Foundations and trends in accounting (Vol. 5, issue 2, pp. 101–147)*. Now Publishers Inc.. https://doi.org/10.1561/109.00000025

Kairos Future. (2017). The Land Registry in the blockchain-testbed. https://static1.squarespace.com/static/5e26f18cd5824c7138a9118b/t/5e3c35451c2cbb6170caa19e/1581004119677/Blockchain_Landregistry_Report_2017.pdf Accessed on 24.04.2021.

Kannengießer, N., Lins, S., Dehling, T., & Sunyaev, A. (2019). Mind the gap: Trade-offs between distributed ledger technology characteristics. http://arxiv.org/abs/1906.00861.

Karjalainen, Risto (2020). *Governance in Decentralised Networks, SSRN Electronic Journal, 1–35*.

Katina, P. F., Keating, C. B., Sisti, J. A., & Gheorghe, A.v. (2019). Blockchain governance. *International Journal of Critical Infrastructures, 15*(2), 121–135. https://doi.org/10.1504/IJCIS.2019.098835.

Kavanagh, D., & Ennis, P. J. (2020). Cryptocurrencies and the emergence of blockocracy. *The Information Society, 36*(5), 290–300. https://doi.org/10.1080/01972243.2020.1795958.

Kim, S. K., & Huh, J. H. (2020). Blockchain of carbon trading for UN sustainable development goals. *Sustainability (Switzerland), 12*(10). https://doi.org/10.3390/SU12104021.

Kitchenham, B., & Charters, S. (2007). Guidelines for performing Systematic Literature Reviews in Software Engineering|BibSonomy. In *Keele University and Durham University Joint Report, (EBSE 2007–001)*. https://www.bibsonomy.org/bibtex/227b256010a48688388374cf83b619b54/msn.

Lacity, M. (2018). Addressing key challenges to making enterprise blockchain applications a reality. *MIS Quarterly Executive, 17*(3). https://aisel.aisnet.org/misqe/vol17/iss3/3.

Lafourcade, P., & Lombard-Platet, M. (2020). About blockchain interoperability. *Information Processing Letters, 161*, 105976. https://doi.org/10.1016/j.ipl.2020.105976.

Meijer, D., & Ubacht, J. (2018, May 30). The governance of blockchain systems from an institutional perspective, a matter of trust or control? *ACM International Conference Proceeding Series.*. https://doi.org/10.1145/3209281.3209321.

Meunier, S. (2018). Chapter 3 - Blockchain 101: What is Blockchain and how does this revolutionary technology work? In A. Marke (Ed.), Transforming climate finance and green investment with Blockchains (pp. 23–34). Academic Press. Doi:https://doi.org/10.1016/B978-0-12-814447-3.00003-3.

Miscione, G., Goerke, T., Klein, S., Schwabe, G., & Ziolkowski, R. (2019). Hanseatic governance: Understanding Blockchain as organizational technology. In *40th international conference on information systems*. ICIS. https://doi.org/10.5167/uzh-177370.

Miscione, G., Ziolkowski, R., Zavolokina, L., & Schwabe, G. (2018). Tribal governance: The business of blockchain authentication. http://hdl.handle.net/10125/50455.

Miyachi, K., & Mackey, T. K. (2021). hOCBS: A privacy-preserving blockchain framework for healthcare data leveraging an on-chain and off-chain system design. *Information Processing and Management, 58*(3), 102535. https://doi.org/10.1016/j.ipm.2021.102535.

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. https://bitcoin.org/bitcoin.pdf.

Nicolae-Bogdan-Cristian, T., Luca, S. A., & Pungila, C. (2020). Towards efficient governance in distributed ledger systems using high-performance computational nodes. In *Proceedings - 2020 22nd international symposium on symbolic and numeric algorithms for scientific computing, SYNASC 2020* (pp. 294–301). https://doi.org/10.1109/SYNASC51798.2020.00054.

Ølnes, S., Ubacht, J., & Janssen, M. (2017). Blockchain in government: Benefits and implications of distributed ledger technology for information sharing. In *Government information quarterly (Vol. 34, issue 3, pp. 355–364)*. Elsevier Ltd. https://doi.org/10.1016/j.giq.2017.09.007.

Osborne Stephen, P., & Strokosch, Kirsty (2013). It Takes Two to Tango? Understanding the Co-Production of Public Services by Integrating the Services Management and Public Administration Perspectives. *British Journal of Management, 24*(S3), 1–28.

Ozdemir, A. I., Ar, I. M., & Erol, I. (2020). Assessment of blockchain applications in travel and tourism industry. *Quality and Quantity, 54*(5–6), 1549–1563. https://doi.org/10.1007/s11135-019-00901-w.

Paech, P. (2017). The governance of blockchain financial networks. In *Modern law review (Vol. 80, issue 6, pp. 1073–1110)*. Wiley-Blackwell. https://doi.org/10.1111/1468-2230.12303.

Parkin, J. (2019). The senatorial governance of bitcoin: Making (de)centralized money. *Economy and Society, 48*(4), 463–487. https://doi.org/10.1080/03085147.2019.1678262.

Pierre, J., & Peters, B. G. (2000). *Governance, politics and the state - (illustrated)* (p. 2000). Macmillan Education UK.

Pimentel, E., & Boulianne, E. (2020). Blockchain in accounting research and practice: Current trends and Future opportunities*. *Accounting Perspectives, 19*(4), 325–361. https://doi.org/10.1111/1911-3838.12239.

Razzaq, A., Khan, M. M., Talib, R., Butt, A., Hanif, N., Afzal, S., & Razeen, M. (2019). Use of Blockchain in governance: A systematic literature review. International Journal of Advanced Computer Science and Applications, 10. Doi:10.14569/IJACSA.2019.0100585.

Reijers, W., Wuisman, I., Mannan, M., de Filippi, P., Wray, C., Rae-Looi, V., … Orgad, L. (2018). Now the code runs itself: On-chain and off-chain governance of blockchain technologies. *Topoi, 37*, 17. https://doi.org/10.1007/s11245-018-9626-5.

Reyes, C. L. (2021). (Un)Corporate Crypto-Governance. *Actual Problems of Economics and Law, 15*(1). doi:10.21202/1993-047X.15.2021.1.135-173.

Rikken, O., Janssen, M., & Kwee, Z. (2019). Governance challenges of blockchain and decentralized autonomous organizations. *Information Polity, 24*(4), 397–417. https://doi.org/10.3233/ip-190154.

Roberts, A. (2020). Bridging levels of public administration: How macro shapes Meso and Micro. *Administration and Society, 52*(4), 631–656. https://doi.org/10.1177/0095399719877160.

Rodrigues, D., Meirelles, F., & Cunha, M. A. (2018). *Benefícios do Blockchain para moedas sociais digitais*.

Schaffers, H. (2018). The relevance of Blockchain for collaborative networked organizations. *IFIP Advances in Information and Communication Technology, 534*, 3–17. https://doi.org/10.1007/978-3-319-99127-6_1.

Shah, S., & Jansen, S. (2021). A framework for designing self-sustaining ecosystems with Blockchain. *Lecture Notes in Business Information Processing, 407*, 184–192. https://doi.org/10.1007/978-3-030-67292-8_14.

Shermin, V. (2017). Disrupting governance with blockchains and smart contracts. *Strategic Change, 26*(5), 499–509. https://doi.org/10.1002/jsc.2150.

Singh, J., & Michels, J. D. (2018). Blockchain as a service (BaaS): Providers and trust. In *Proceedings - 3rd IEEE European symposium on security and privacy workshops, EURO S and PW 2018* (pp. 67–74). https://doi.org/10.1109/EuroSPW.2018.00015.

Stephan, Mark., Graham, Marshall., Michael, McGinnis., 2019. An Introduction to Polycentricity and Governance. In Governing Complexity, edited by Thiel, Andreas., Blomquist, William, A., Garrick, Dustin, E., 21–44. Cambridge University Press.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Thousand Oaks, CA: Sage.

Treib, Oliver, Holger, Bähr, & Gerda, Falkner (2007). Modes of Governance_ Towards a Conceptual Clarification. *Journal of European Public Policy, 14*(1), 1–20.

Tozzi, C. (2019). Decentralizing democracy: Approaches to consensus within blockchain communities. *Tozzi C. Teknokultura, 16*(2), 181–195. https://doi.org/10.5209/TEKN.64523.

Trbovich, A. S. (2019). In pursuit of good governance for the energy industry blockchain. Journal of Energy Markets, 12(2), 1–17. Doi:10.21314/JEM.2019.192.

Trump, B. D., Florin, M. V., Matthews, H. S., Sicker, D., & Linkov, I. (2018). Governing the use of Blockchain and distributed ledger technologies: Not one-size-fits-all. *IEEE Engineering Management Review, 46*(3), 56–62. https://doi.org/10.1109/EMR.2018.2868305.

Van Pelt, R., Jansen, S., Baars, D., & Overbeek, S. (2021). Defining Blockchain governance: A framework for analysis and comparison. *Information Systems Management, 38*(1), 21–41. https://doi.org/10.1080/10580530.2020.1720046.

Wang, S., Ding, W., Li, J., Yuan, Y., Ouyang, L., & Wang, F. Y. (2019). Decentralized autonomous organizations: Concept, model, and applications. *IEEE Transactions on Computational Social Systems, 6*(5), 870–878. https://doi.org/10.1109/TCSS.2019.2938190.

Wang, Y. (2019). Designing a blockchain enabled supply chain. *IFAC-PapersOnLine, 52*(13), 6–11. https://doi.org/10.1016/j.ifacol.2019.11.082.

Werbach, K. (2018). *The blockchain and the new architecture of trust*. Cambridge, Massachusetts: The MIT Press.

Werbach, K. (2020). The Siren song: algorithmic governance by blockchain. In K. Werbach (Ed.), *After the digital tornado: Networks, algorithms, humanity (pp. 215–240)*. Cambridge University Press. DOI:Undefined.

Williamson, O. E. (1993). Calculativeness, trust, and economic organization. *Journal of Law, Economics, and Organization, 36*(1), 453–486.

Yeung, K., & Galindo, D. (2019). Why do public blockchains need formal and effective internal governance mechanisms? *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3427763.

Zachariadis, M., Hileman, G., & Scott, S.v. (2019). Governance and control in distributed ledgers: Understanding the challenges facing blockchain technology in financial services. *Information and Organization, 29*(2), 105–117. https://doi.org/10.1016/j.infoandorg.2019.03.001.

Zhang, P., White, J., Schmidt, D. C., & Lenz, G. (2017). Applying software patterns to address interoperability in Blockchain-based healthcare apps. *ArXiv*. http://arxiv.org/abs/1706.03700.

Ziolkowski, R., Miscione, G., & Schwabe, G. (2020). Decision problems in Blockchain governance: Old wine in new bottles or walking in someone Else's shoes? *Journal of Management Information Systems, 37*(2), 316–348. https://doi.org/10.1080/07421222.2020.1759974.

Dr. Evrim Tan is a post-doctoral researcher in KU Leuven Public Governance Institute. Stanislav Mahula is a PhD candidate at KU Leuven Public Governance Institute. Prof. dr. Joep Crompvoets is professor and research manager at KU Leuven Public Governance Institute holding the chair on 'information management in the public sector'.