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TITLE

The State-of-the-art of the Research Methodology on Blockchain Technology:

Proposal for a Research Agenda and Policy Implications

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Abstract

Blockchain technology is a disruptive innovation that can profoundly impact the economy, institutions, and society. However, research on this topic is still emerging, and the literature is still fragmented. Amid the uncertainty, the study proposes a general framework for analysis and a comprehensive assessment of the research state-of-the-art. The thesis is organized as follows.

Chapter 1 introduces the basic concepts and features of blockchain technology. It discusses some hypotheses about the methodologies that can be used for literature reviews. A systematic mapping study has been conducted to develop a meta-analysis of research methodologies applied to blockchain research. The study provides relevant findings from the content of the articles collected, such as trends and gaps in the literature, strengths and weaknesses of the research methodologies, and implications for future research. The literature has been mainly focused on system efficiency, legal, trust, cybersecurity, and governance implications. However, it also contributes considerably to the debate in various relevant disciplines by introducing new themes and opportunities and evaluating its potential utilization in different sectors and fields. Furthermore, the study highlights a gap in the core analysis of the real-world impact, especially about the economic consequences of blockchain technology adoption.

Chapter 2 focuses on opportunities and challenges from the policymaker's perspective and provides insights and recommendations for public authorities interested in further exploring the potential benefits of this technology. It also explores the most relevant fields of application and potential implementations of blockchain technology in various sectors, such as finance, supply chain, health care, education, energy, and governance, highlighting some benefits of using blockchain in these domains. As for the public sector, two case studies are proposed to illustrate how blockchain can improve efficiency, transparency, security, and trust in public services and administration. However, blockchain poses challenges and limitations, such as scalability, interoperability, regulation, education, and adoption. Therefore, policymakers need to carefully assess the opportunities and risks of blockchain technology for their specific contexts and objectives. They must also collaborate with other stakeholders, such as researchers, developers, businesses, and civil society, to create an enabling environment for blockchain innovation. Finally, it is crucial to foster collaboration and coordination among distinct levels of government as well as with other countries and regions on blockchain policy issues.

Chapter 3 presents a tentative analysis of the determinants influencing the demand for grants for blockchain-related projects from organizations resident in the European Union and associated countries accessing funds from the EU framework programs. Using a fixed-effects panel data model, the study estimates the impact of demographic, social, educational, economic, political, and institutional factors on the amount of EU grants for blockchain-related projects over the available time period 2015-2023 among 33 countries (297 observations in total). The results suggest that the adoption and diffusion of this technology (as measured by EU funding) and the willingness to innovate depend on the effort of the research and development sector, the quality of the existing technological infrastructure, the demographic structure of the population, and the economy's flexibility. Also, the policymaker has a crucial role in fostering blockchain adoption since the regulatory framework, government effectiveness, and access to public services are essential in supporting innovation. The policymaker can encourage blockchain adoption by ensuring that regulations are targeted for both consumers and businesses without constraining their initiatives, providing public resources for research and development, and promoting education, training, and awareness-raising on blockchain technology and its applications. However, no clear pattern or trend can be observed except for increasing attention to this technology. This suggests there is still much uncertainty and experimentation in this field.

Keywords:

Blockchain Technology, Empirical Analysis, European Union, Public Services, Innovation.

SUMMARY

INTRODUCTION

Blockchain technology is a transparent and decentralized system of recording lists of transactions. It is based on distributed ledger technology, consisting of a *"distributed transactional database secured by cryptography and governed by a consensus mechanism"* [1]. It can be considered a system of record of digital information.

The first blockchain application is Bitcoin, a public and permissionless ledger that enables transferring information and coins without an intermediary [2]. The launch of Bitcoin in January 2009 initially had no significant impact on sectors other than computing technology. In a few years, its value increased dramatically and attracted the attention of researchers and the financial market [3].

As many users and businesses have started to adopt cryptocurrencies as a certified payment method, the debate around the use and advantages of cryptocurrencies and digital currencies has been the primary driver to stimulate blockchain research. However, this technology has emerged in recent years as an innovative framework for interactions and transactions in several fields of application. Such a large-scale diffusion has prompted governments, financial institutions, and economic actors to reflect on political, legal, economic, and financial consequences as well as social and cultural implications [4]. Blockchain is a remarkable case of how disruptive innovation can profoundly impact the socio-economic and cultural system [5].

Numerous studies on blockchain technology have been conducted in the last few years. Today we are witnessing a proliferation of new infrastructures and applications in different fields and sectors, looking for feasible business models [6].

At this stage, blockchain research still needs to be more extensive, and the future of this technology is still uncertain. Research mainly focuses on case studies and applied methodologies [6]. In addition, the scientific literature is still trying to define a development trajectory and frame the consequences that blockchain might have in the coming years. In particular, there is a need for studies oriented to the policymaker's perspective. Although substantial literature identifies different fields of application, it is challenging to recognize organic and comprehensive studies on impact assessment tools and potential practical policy implications at first sight [7].

The academic literature has been mainly focused on efficiency, security, legal, trust, and governance implications. Still, it also contributes significantly to the debate in various relevant disciplines by introducing new themes, opportunities, and fields of application and evaluating its potential impact on different sectors [8, 9].

Blockchain technology is a groundbreaking innovation that can transform society and the economy. However, research on this topic is still emerging, and a comprehensive and systematic overview of the research methodologies applied to the blockchain is needed.

In this phase, the research could play a vital role in identifying and analyzing the most controversial aspects - and the benefits that its introduction could bring in terms of efficiency performances – to remove or reduce potential limitations and emphasize the positive impacts not only for firms and users but also for governments and the public sector in general. This approach would help highlight those factors that improve the acceptance intention and trust of all actors involved. A further contribution might come from elaborating suggestions, measures, and policies to facilitate its practical and reasonably accepted application for public institutions and other authorities.

A comprehensive assessment of state-of-the-art blockchain research needs to be developed, and this area needs to be improved. The absence of a shared framework and the lack of a holistic evaluation of the current research progress makes it even more challenging to support the evolution and development of the technology itself, which is affected by numerous practical and theoretical obstacles. Research could also help discuss the critical issues that organizations are called upon to address and what methodology should be used to tackle the debate on its potential implementation [10].

Therefore, this study aims to conduct a meta-analysis of research methodologies applied to blockchain research to elaborate a comprehensive assessment of the research state-of-the-art. Furthermore, it provides insights and recommendations for policymakers interested in exploring this technology's opportunities and challenges. It is organized as follows.

Starting from the original paper by Satoshi Nakamoto [2], the anonymous creator of Bitcoin, in Chapter 1, we will introduce the basic concepts and features of blockchain technology, such as distributed ledger, cryptography, consensus mechanisms, and types of blockchain. It also provides some examples of blockchain infrastructures in different domains. As for the initial step of the research, we will discuss some hypotheses about the methodologies that can be used for literature reviews and the key features of a systematic mapping study. This method allows for examining the most prevalent methodologies for reviewing blockchain research. It might also help identify, classify, and analyze the main features, strengths, weaknesses, challenges, limitations, fields of application, policy implications, and the literature's influence on the development trajectory [11]. The results of the systematic mapping study include the number and distribution of publications by year and sector, the primary sources and outlets, the research topics and questions, and the research methods and techniques adopted. Also, it provides findings from the content of the selected articles, such as trends and gaps in the literature, strengths, and weaknesses of the research methodologies, and implications for future research.

Chapter 2 focuses on the policymaker's perspective and provides an overview of the benefits and challenges of blockchain technology. It also offers valuable recommendations for addressing the debate on introducing blockchain in the public sector and fostering innovation and stakeholder collaboration. We will explore the most relevant fields of application and potential implementations of blockchain technology in various sectors, such as finance, supply chain, health care, education, energy, and governance. It also highlights some benefits and challenges of using blockchain in these domains. As for the public sector, two case studies are proposed: one on digital infrastructure for the pension system in the Netherlands and one on social welfare vouchers in the town of Groningen. These case studies illustrate how blockchain can improve efficiency, transparency, security, and trust in public services and administration. Finally, we will synthesize the results and findings from the policymaker's perspective.

Chapter 3 explores the role of European institutions in promoting and regulating blockchain technology and its applications. It will introduce the main initiatives and funding programs of the European Union and offer additional data on the distribution by year, sector, and country. A panel data econometric model has been used to assess the main drivers that facilitate blockchain implementation and the role of the policymaker in addressing potential limits. The model uses data from thirty-three countries for nine years. The analysis includes innovation, economics, regulation, infrastructure, education, and social acceptance indicators.

CHAPTER 1: THE STATE-OF-THE-ART OF RESEARCH ON BLOCKCHAIN

1.1 Blockchain Technology: Definition and key features

Blockchain technology removes the existence of a private ledger and an intermediate by generating a public, immutable, encrypted, distributed ledger. This means that each user in the system can create contracts and verify each transaction's ownership and validity [12]. The object of this section consists of a description of blockchain technology, what it is and how it works, and an in-depth overview of the key features and different consensus mechanisms with their benefits and limitations, intending to elaborate a clear picture of blockchain technology development state-of-the-art.

A blockchain protocol was conceptualized for the first time in 1982 by David Chaum [13] and then developed by Haber and Stornetta in the early '90s [14]. However, its fame is mainly due to its application to Bitcoin and the paper published by its anonymous creator Satoshi Nakamoto [2]. The spread on a global scale of cryptocurrencies as speculative financial instruments – such as Ethereum, Ripple, and others - supported by the unpredictable increase in their value observed in the last decade has made it necessary to study this innovation and investigate its impact on different fields.

The issues related to blockchain technology are partially at an early stage; its diffusion and application to different fields have posed the basis for disruptive innovation with the ability to redesign mainstream methods to transact information and business or manage assets [5]. The acknowledgment is primarily due to the robustness and effectiveness of the underlying technology, characterized by reliability, trustworthiness, and distribution, and its ability to create a network of data and records that make transactions more immediate and valuable, affecting how society organizes relationships. The advantage also consists of reducing the involvement of a trusted third party - or an intermediate - necessary to enforce the execution and functioning of the infrastructure without any negative implication regarding data protection, cyber-attacks, or fraud risks [15]. In this respect, this also figures out a suspicious attitude by the authorities who fear its application could somehow reduce their ability to control economic and political dynamics or other related issues [16].

Most of the features of blockchain technology have been introduced in the white paper published by the anonymous creator of Bitcoin, Satoshi Nakamoto [2]. In their article, they create a narrative on how a cryptocurrency based on distributed ledger technology could work. He also considers some of the governance, consensus, and trust implications. The fame of the publication is mainly due to the ability of the author to adopt a language and a rationale that are easily understandable also by non-experts. This lack of complexity has eased the paper's diffusion and deployment as a *manifesto* for blockchain technology and cryptocurrencies.

The article briefly overviews some benefits and challenges of a peer-to-peer electronic cash system. According to Nakamoto, the traditional financial system's limitations that rely on trusted third parties to process electronic payments can be overcome with a cryptographic proof-based electronic payment system that enables two willing parties to exchange money directly without an intermediary. Transactions require high computational power to reverse, and the architecture would safeguard parties from fraud and standard escrow procedures could be easily applied to protect both buyers and sellers. This new system would avoid fraud by making transactions tough to reverse and could also employ simple escrow methods to protect buyers. The suggested solution relies on *"a peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions."* The system is resilient to intrusions and attempts to modify it if nodes that act honestly employ more computational power than untrusty nodes.

In simpler terms, banks and other financial institutions process electronic payments in the current economic system. However, this system has limitations, such as high transaction costs and the need for trust between parties. The author proposes a new payment system that uses cryptographic proof instead of trust to allow direct transactions between parties without needing a trusted third party. This new system would be more secure and less costly than the current system[1].

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[1] As Nakamoto writes: *"Commerce on the Internet has come to rely almost exclusively on financial institutions serving as trusted third parties to process electronic payments. While the system works well enough for most transactions, it still suffers from the inherent weaknesses of the trust-based model. Completely non-reversible transactions are not really possible since financial institutions cannot avoid mediating disputes. The cost of mediation increases transaction costs, limiting the minimum practical transaction size and cutting off the possibility for small casual transactions, and there is a broader cost in the loss of ability to make non-reversible payments for non-reversible services. With the possibility of*

The analysis explains the main features of the technology and, in particular, how transactions work, the main characteristics of a timestamp server, the proof-of-work consensus mechanism, the framework on which the network is based, potential incentives to act honestly, and more details on the required disk space, the payment verification system, privacy issues, and calculations.

For the sake of simplicity, we will use an example. When two users (A and B) want to exchange a coin, this action would determine the creation of a contract that describes the transaction from user A to user B. This contract is signed by A, and the transaction can be recorded by a document that verifies the transaction's validity. This document is proof of the contract's validity. However, at this stage, it can be invalidated – for example, by potentially generating a duplicate of the contract with a third party: this would generate ambiguity and create the risk of having other claims on user A's coins. It is possible to reduce ambiguity by introducing new features, such as a unique serial number associated with each coin. In this case, the contract between A and B will consist of a transaction of the coin number X (not just a generic reference to an unidentified coin). B can verify the ownership by consulting a ledger. If B accepts the transfer, the system will move coin X from A to B and register a new transaction in the ledger. In a classical financial system, banks would work as the intermediate that verifies the ownership of the coin, the signature of the contract, and the transaction, registering the movement from A's account to B's account. They will have the role of managing the (private) ledger.

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reversal, the need for trust spreads. Merchants must be wary of their customers, hassling them for more information than they would otherwise need. A certain percentage of fraud is accepted as unavoidable. These costs and payment uncertainties can be avoided in person by using physical currency, but no mechanism exists to make payments over a communications channel without a trusted party.
What is needed is an electronic payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party. Transactions that are computationally impractical to reverse would protect sellers from fraud, and routine escrow mechanisms could easily be implemented to protect buyers. In this paper, we propose a solution to the double-spending problem using a peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions. The system is secure as long as honest nodes collectively control more CPU power than any cooperating group of attacker nodes."

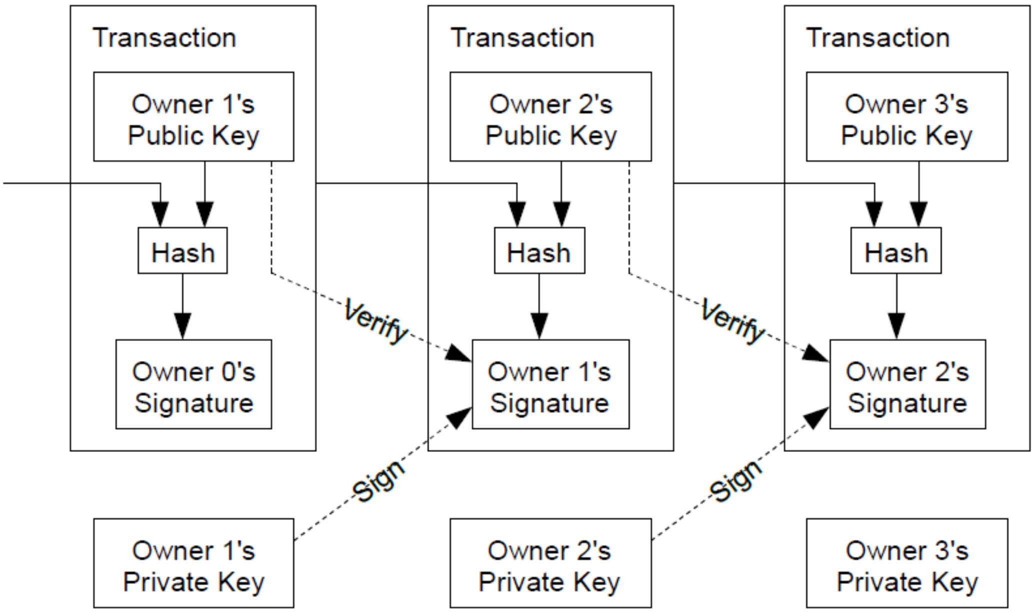

Figure 1 – Transaction system (source: Nakamoto, S., 2008)

In Nakamoto's paper, the author discusses how this mechanism could work when you use an electronic coin without an intermediate, hence in the case of Bitcoin.

Blockchain technology is the broader category that Bitcoin belongs to. Its definition is based on its technical features. The European Central Bank defines the blockchain as *"the ledger (book of records) of all transactions, grouped in blocks, made with a (decentralized) virtual currency scheme"* [17]. For example, a Bitcoin block contains information about the previous owner, the new owner, and the number of bitcoins going to be transferred. More generally, a blockchain is a continuous *"sequence of blocks which holds a complete list of transaction records like conventional public ledger"* [18]. Each user (or computer) connected to the network is a single node of a peer-to-peer network along which the decentralized technology is distributed; thus, each node is constantly updated. In this way, the whole blockchain is not stored in a unique central location [19]. Therefore, the ledger would be a distributed storage of multiple identical copies of the same blockchain. The block located at the beginning of the chain is named the "Genesis block". All blocks are linked and point to the previous one (called "parent block") through a digital reference to the parent block's hash value[2] [15]. Thus, each

[2] In cryptography, a "hash value" is the result of a cryptographic hash function that is a mathematical function – hence an algorithm - that maps a data input of arbitrary size or variable lengths and returns a fixed-size output called a hash value.

block has a hash, which is unique for each block. According to Nakamoto, a block consists of the block header and the block body. In particular, the block header includes the following features: Block version, Parent block hash, Merkle tree root hash, Timestamp, nBits, Nonce, and Calculation:

- Block version: indicates which set of block validation rules to follow.
- Parent block hash: a 256-bit hash value that points to the previous block.
- Merkle tree root hash: the hash value of all the transactions in the block.
- Timestamp: current timestamp as seconds since 1970-01-01T00:00 UTC.
- nBits: current hashing target in a compact format.
- Nonce: a 4-byte field, which usually starts with 0 and increases for every hash
- Calculation.

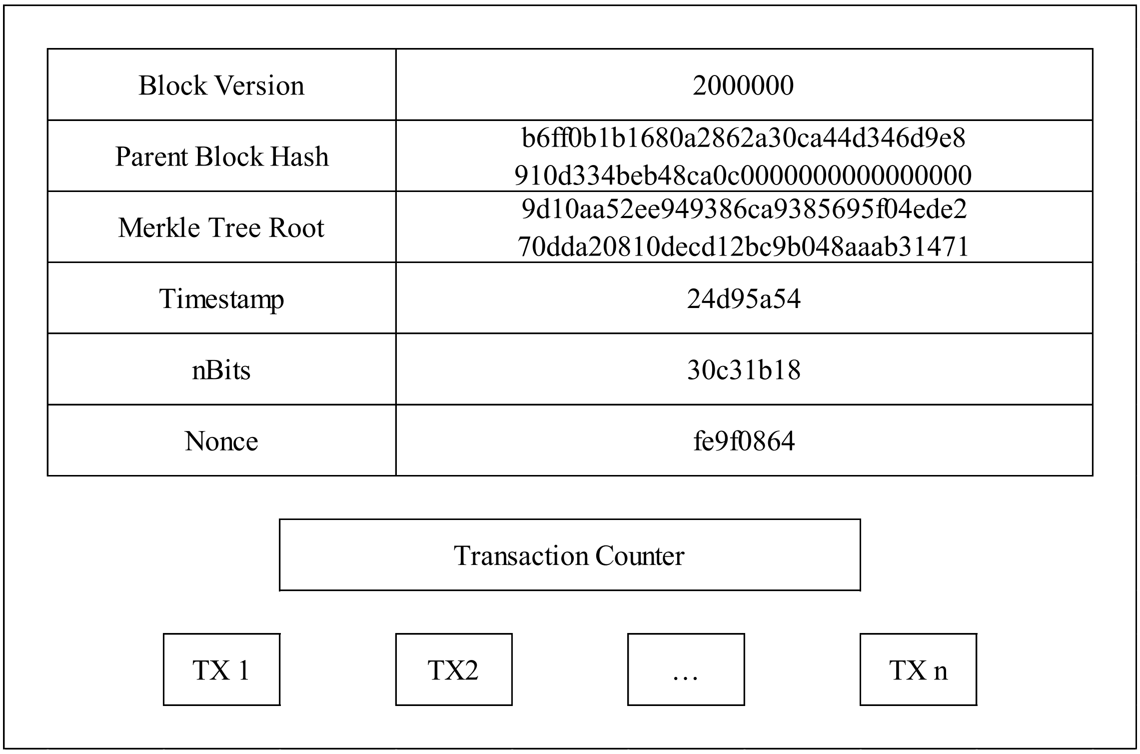

Figure 2 - Block Structure (source: Zheng, et al., 2018)

In the block body, we can find a transaction counter and a record of all the block transactions. The block size determines how many transactions can be recorded in the block body. Blockchain uses an asymmetric cryptography mechanism to validate the authentication of transactions [20]. A pair of keys is assigned to each user – private and public. Transactions are signed using the private one. When user A - the current owner -

wants to transfer the coin to user B, he adds to the end of the coin (that is, a block) the previous transaction and the public key of the new owner by digitally signing a hash with user A's private key. A digital signature based on asymmetric cryptography is used in an untrustworthy environment [15].

The digitally signed transactions are sent throughout the whole network, and after that, they can be accessed by public keys, which are accessible to all users in the chain. Thus, the transaction will be regulated in the following way: User A is the coin X's owner, and this information is registered in the distributed ledger; in this case, we will have two keys – one for the coin and one for the ownership statement; user A decide to transfer coin X to user B; if user B accepts the transaction, we will have a new record with its specific key that certificate that coin X - with its unique serial key - is now the property of user B. If any other user wants to buy the same coin X, user A cannot transfer it because everybody can check the ownership and the right to use and transfer it[3].

Blockchain technology has the following key features [15]:

- Decentralization. Traditional centralized transaction systems require a central authority or trusted agency to validate the contract. In a blockchain network, any pair of peers (peer-to-peer) con execute a transaction without authentication by the intermediary. This process significantly reduces server costs and partially mitigates the central server's performance bottlenecks. There is no longer a need for a third party. The different consensus mechanisms describe how data consistency is maintained in the distributed ledger. Potential benefits: efficiency.
- Persistency. Each transaction that has been validated cannot be deleted once it has been included in the chain, and miners would not admit an invalid transaction. Since each transaction sent to the blockchain needs to be accepted and recorded in blocks distributed in the whole network, it is hard to tamper. Additionally, other nodes would validate each broadcasted block, and transactions can be verified. So, any untrustworthy behavior can be easily

[3] As to Zheng et al. [15]., the typical digital signature involves two phases: signing and verification. *"When user A wants to sign a transaction, she first generates a hash value derived from the transaction. She then encrypts this hash value b using her private key and sends the encrypted hash to another user B with the original data. B verifies the received transaction by comparing the decrypted hash (by using A's public key) and the hash value derived from the received data by the same hash function as A's".*

identified and signaled. In practice, if someone tries to attack a block or make some modification, the block's hash value would change, and all subsequent blocks must be modified. To this extent, a certain amount of computational power is needed, but it would be significant enough to avoid a single node being able to do it. Some authors refer to this feature as immutability. Potential benefits: reliability, immutability.

- Anonymity. Users can operate and interact with the blockchain through an anonymous address that allows them to hide their identity. There is no longer any central authority storing users' confidential information. This mechanism enforces privacy on the information contained in the block and the blockchain. Potential benefits: security.
- Auditability. Any transaction contains a reference to previous transaction history. Considering that each transaction on the blockchain is certificated and recorded with a timestamp, all users can potentially verify and trace the earlier records by accessing the network through any node in the distributed chain. Potential benefits: accountability, transparency.

Different blockchain technologies can be grouped into three typologies according to the degree of control: public, permissioned (consortium or hybrid), and private [15, 21]. Other authors distinguish only permissioned and permissionless [22, 23].

- Public blockchain. They operate with a freely joinable network and an open protocol. The self-governed network tries to incentivize miners to validate transactions using their computational power. They are fully decentralized, censorship-resistant, the most accessible, and all transactions are visible and transparent. In contrast, the energy required is sensitively high, and transactions are technically traceable – even if anonymity is preserved.
- Private blockchain. Invitation-only networks where a central entity controls allowances and assigns roles to participants. They are well-suited for organizations and corporations seeking a protocol with limited access. The main advantages are increased security; easier to scale – given that the central authority can quickly implement changes and features, usually smaller, faster, and more trusted since every participant is identified. Disadvantages are lack of decentralization and immutability.
- Permissioned (or consortium or hybrid) blockchain. They need that an authority (not necessarily a single central authority) gives users permission to

join and execute distinct functions. However, unlike private blockchains, everybody can ask for access, regardless of their real identity, and other roles can be assigned. Main advantages: better performance than public blockchains because of their size; level of decentralization and governance structure can vary; customizability; light governance, which means that the authority can operate changes without asking the network. Main disadvantages: They require external storage space since their size is more significant than private ones; the degree of security can vary depending on the verification of identities, so there is space for manipulation.

The three different typologies cannot be considered in competition with each other. As we described, they present various features, advantages, and disadvantages and try to achieve a specific aim and suit unique needs. Each organization should discuss which is the best type that can best serve its purpose.

As already said, the consensus mechanism tries to resolve concerns about the possibility of a double-spent coin. Nakamoto's paper introduces the problem by making an example of traditional currencies. They are issued by the Mint (or the central bank), the only trusted authority able to verify that a coin is not doubled. In the case of Bitcoins, the only way to avoid double spending is to record and be aware of all transactions. Moreover, this is possible only if each transaction is immediately and publicly announced so that all users can agree on the same identical transaction history. Digital currencies and cryptocurrencies are usually based on a distributed ledger technology that keeps and validates multiple copies of a ledger across an IT network. Each node contains a full copy of all the transactions record ever made, linked together and spare through the peer-to-peer IT network [24]. We can easily understand that each user in the network can check the database, and this process would not be sufficient to modify any information in the ledger. Indeed, the approval of all nodes is required to change some feature of any already recorded transaction – and this would be too expensive or even impossible in practical terms.

More specifically, the solution adopted for the Bitcoin technology uses a timestamp server. *"A timestamp server takes a hash of a block of items to be timestamped and widely publishes the hash [...]. The timestamp proves that the data must have existed at the time in order to get into the hash. Each timestamp includes the previous timestamp in its hash, forming a chain, with each additional timestamp reinforcing the ones before it"* [2]. Although hashes are used to prevent tampering, they are not sufficient due to the high-speed calculation power of modern computers. As a possible solution, blockchain uses the concept of "Proof-of-Work" (PoW). This consensus mechanism requires that network members participate in solving an algorithm, using their computational powers, and engaging in hashing functions.

As we said, a hash is a fixed-sized code made of a certain number of zeros followed by a sequence of numbers and letters different from zero[4]. The hash corresponds to a block containing a defined number of Bitcoins and transactions as well as the previous block in the chain. Changing just partial information would generate a new hash that the network would reject. Users connected to a network would spend work in terms of computational power to resolve the algorithm that returns exactly the identical hash in that block. The consensus mechanism requires calculating a value equal to or smaller than the hash value. The more power you use, the more quickly you get the hash. Once the puzzle is solved and a valid hush is found, it is broadcast to the network so that the block can be added as the new and last block of the chain.

This mining process can be considered the consensus mechanism on which Bitcoin is based. This mechanism works when the network creates a new coin and when the coin is transferred between two users. Indeed, you can receive the reward of newly created bitcoins by offering your computing power proportionally to work done, and this is an incentive to participate in the network and to act honestly by recording only valid transactions. Considering that the ledger contains a record of all Bitcoin transactions built as a sequence of blocks, and since each hash is written in a block and all the followers, when someone tries to change a block, all the following blocks would lose their connection with the previous ones. However, the ledger is public and distributed; thus, the majority of the other users would reject an altered version of the chain. Even if a single miner could collect enough power to alter the blockchain by gaining a majority, the miner should choose whether to mine bitcoins honestly participating in the network – with the highest probability to get a reward – or altering the chain and undermining the trust in the system.

The Proof-of-Work adopted by Bitcoin requires relatively high energy power and resources. Many protocols have been implemented to reduce the loss, and other architectures have been designed among blockchain technologies [15].

[4] An arbitrary example of a hash for a generic block #1234567, mined on a specific date, would be 0000000000000000000005caf078f12c69a445dfe30dbb5aaa4b9d94e7b37a2.

An efficient alternative is the Proof-of-Stake (PoS). The mechanism requires that users who own a certain number of coins prove the ownership itself. Thus, the majority is reached when the majority of coins have been verified. In this case, the wealthiest people would dominate the network since she is incentivized to prove their ownership. At this point, there are different methods to assign the new block: Blackcoin uses randomization by combining the lowest hash value with the size of the stake [25], Peercoin prefers a coin age-based criterion where the larger the sets of coins higher the probability to get a new one. Since PoS saves energy and has lower mining costs, the attempts to attack it are considerably high. For these reasons, many blockchains adopt PoW early in their development and later transform to PoS. This is the case for Ethereum [26].

Bentov et al. [27] described a mechanism that combines PoS and PoW, called Proof-of-Activity (PoA). The protocol requires that N miners sign a block to validate it; in this way, a potential owner of more than 50% of coins cannot individually control the creation of new blocks.

In the case of Proof-of-Capacity, the requirement to mine blocks is allocating hard drive space [28].

Other mechanisms are based on fault tolerance, like the Practical byzantine fault[5] tolerance (PBFT), utilized from Hyperledger Fabric, where mining is a tri-phase process: each phase requires that more than two-thirds of all nodes vote to move the new node to the following stage. This new node would be “acknowledged” by the majority of the network [15]. A similar mechanism can be recognized in the Stellar consensus protocol (SCP), where participants can make the decision to believe a group of other participants [7]. An evolution of this scheme is Antshares which developed the delegated byzantine fault tolerance (dBFT), where just a few nodes vote instead of the entire network [15]. We do not need a hashing procedure in all these cases: each node has to query or choose other nodes.

[5] This name is due to the Byzantine General Problem [39], a situation in which a group of generals must decide whether to attack the city. The attack’s success depends on the number of generals who choose to attack, but traitors can be hidden among them. They can communicate a false decision to the rest of the group, thus determining the failure of the operation.

In the case of Primecoin, the method used can be called "Proof-of-burn" [15] since coins must be sent by miners to an address and cannot be retrieved. Miners are compensated by receiving a chance to mine blocks as a reward.

Alternative protocols are the Delegated proof of stake (DPOS) used by Bitshares, which is a similar mechanism of PoS (the probability depends on the amount of owned coins) but with a delegation method in which a set of users (decided by others) is allowed to mine a new block – and she can be easily removed if necessary [29].

Tendermint is a byzantine consensus algorithm similar to PBFT but with locked coin validators. The process consists of a round in which a user-proposer who wants to mine a coin gets permission to broadcast a block, but the block still needs to be confirmed. Thus, you need to know all nodes for selection by the user-proposer. We will have three subsequent steps: (1) pre-vote: validators choose whether to broadcast a pre-vote for a block; (2) pre-commit: if the node has more than two-thirds of pre-votes, it broadcasts a pre-commit for the selected block; (3) commit: the node validates the block and broadcasts a commit for it; when it received two-thirds of commits, it accepts the block [15, 30].

Finally, we have Ripple, a consensus mechanism based on subnetworks collectively trusted within the network. The network is divided into servers (who participate consensus process) and clients (who transfer funds). The server belongs to a Unique Node List (UNL) that needs to reach and hold an 80% agreement quota to maintain the ledger correctly [15].

The different consensus mechanisms can be compared following some features that they have:

- Node identity management. Does the chain need to know the identity of all or a certain number of nodes, or can the network be joined freely?
- Energy saving. Which amount of energy is needed to resolve the algorithm?
- The tolerated power of the adversary. How much hash power is needed to prevent attacks or gain network control?

This initial glimpse into blockchain technology motivates a deeper exploration of the topic. Depending on the application field and services implemented, the scope, potential, and requirements are far from a resolutive revolution. A literature review is essential to assess better blockchain technology's current challenges, opportunities, and limitations. We can also identify the gaps in knowledge and the areas that need further investigation. A literature review can assist in comparing and contrasting different approaches, methodologies, and perspectives on blockchain technology and assessing their advantages and disadvantages. It can also help to position the research within the broader context and rationalize research questions and objectives.

1.2 Literature Review on Blockchain Research Methodology

Research on blockchain technology is fragmented. The literature has been mainly focused on several issues, such as system efficiency, security, legal, trust, and governance implications. However, it also contributes considerably to the debate in various relevant disciplines by introducing new themes, opportunities, and fields of application and evaluating its potential impact on different sectors [8, 9]. Although the first application of blockchain technology in cryptocurrencies significantly impacts traditional financial services and payment methods [4], the real potential of this innovation is much broader and more profound. The technology is evolving, and further updates are needed to enhance efficiency and effectiveness.

The scientific debate needs to be addressed. A shared framework and the unavailability of a holistic narrative from the research perspective make supporting the discussion even more challenging. In this section, we will provide a meta-analysis of research methodologies applied to blockchain research to elaborate a comprehensive assessment of the research state-of-the-art.

A survey of the research methodology is needed to understand which approach is more suitable to address the disruptive implications for different fields and sectors. A literature review of research methodologies applied to blockchain could provide insight into the framework in which research activity and scientific literature operate, outline the research methodology state-of-the-art, assess the best methodologies for different purposes, and identify potential gaps.

Systematic reviews are *"a form of meta-analysis designed to collect, investigate, and summarize what is known and what is not known about a specific practice-related question"* [31]. To build the review, we need to consider that research on blockchain technology is still being developed, and little progress has been made. For the study, different options have been evaluated according to the classification created by Snyder [31]:

- The first option considers the most common methodology to synthesize findings: systematic literature reviews. Systematic literature reviews have been developed to answer a specific hypothesis question by summarizing the main findings in a defined field using a systematic, transparent, and replicable approach. For their simplicity and effectiveness and for their ability to minimize errors and bias, they are considered the expected standard for building a review. The process's primary applications include collecting and analyzing data and identifying empirical evidence. For example, a systematic literature review could demonstrate the potential impact, whether an effect pervades a context, and could offer insights into future studies that can be conducted to analyze the implications better [32, 31].
- As a second alternative, we considered replicating methodologies applied for the first attempts of building a literature review: a systematic mapping study (or scoping study). A systematic mapping study aims to provide an overview of a research area through classification and counting contributions about the classification groups, eventually establishing if research evidence exists and quantifying the amount of evidence. After defining the research questions, a search protocol is needed to undertake a search. The search protocol includes the selection of appropriate databases and the definition of an algorithm. The approach is remarkably similar to systematic literature reviews. However, the objective differs: systematic mapping studies structure a research area, while systematic literature reviews focus on gathering and synthesizing evidence. According to Petersen et al. [11], the interest in systematic mapping study methodology is increasing yearly. Using this methodology, we will extend the research of the first attempt by Yli-Huumo et al. [33] to different databases. This can be combined with algorithm changes by introducing additional filters or keywords and evaluating the best performing for our purpose. In this way, we could have a relatively small number of papers, but they would still be comprehensive of the main issues that need to be discussed.
- Considering that we aim to build a scoping or a qualitative review (not a descriptive nor a narrative review, and we do not aim to conduct a meta-analysis or quantitative review), a semi-systematic review could also be appropriate. It is designed for topics conceptualized and studied by various

groups of researchers that focus on diverse disciplines that hinder a complete systematic review process. In our case, it would be odd to select all relevant articles, and this approach provides a strategy for addressing complexity. This suit thematic or content and qualitative analysis [31].

- An integrative review would be too premature, considering it enables assessing, critiquing, and synthesizing the literature on a research topic to build theoretical frameworks and address emerging perspectives. Indeed, it enhances the specific topic's theoretical basis as it evolves. However, it is more frequent in the business literature and helpful in addressing mature research fields. The goal of new areas of research is to generate initial or preliminary concepts and theoretical frameworks. Still, this type of review often demands inventive data collection, as the purpose is usually not to include all papers but rather to synthesize views, insights, and perspectives from different fields or research traditions [31, 34].

Building a systematic mapping study is likely the most robust and appropriate approach to identify which methodology could better help strengthen and align learnings since it seems too early to consider a more targeted approach – specific for a more advanced state of development. Also, systematic mapping studies present the practical benefit that the quality of research can be improved further after that knowledge about a specific field of interest (and the number of publications) increases.

In light of this, our initial step has been to study the methodology described by Yli-Huumo et al. [33], who first conducted a systematic mapping study on blockchain research methodology.

The authors used the methodology by Petersen et al. [11] and the guidelines for a systematic literature review following Kitchenham and Charters [35] to only look for relevant papers. The results help find and classify research fields related to Blockchain technology and potential research gaps. As we will see, this article has been a benchmark for all the subsequent studies in this field.

First, the authors established the questions to whom it is necessary to give some valuable answers. The research questions are the following:

- *"RQ1: What research topics have been addressed in current research on Blockchain?"*
- *"RQ2: What applications have been developed with and for Blockchain Technology?"*

- *"RQ3: What are the current research gaps in Blockchain research?"*
- *"RQ4: What are the future research directions for Blockchain?"*

The second step is designing a search protocol that search engines can use to gather all the relevant or impactful publications for the addressed topic. The authors tested possible keywords and various alternatives and concluded by using the keyword "BLOCKCHAIN". Finally, they chose the databases for their research. The selected databases were: (1) IEEE Xplore, (2) ACM Digital Library, (3) Springer Link, (4) ScienceDirect, (5) Ebsco, and (6) PLOS One.

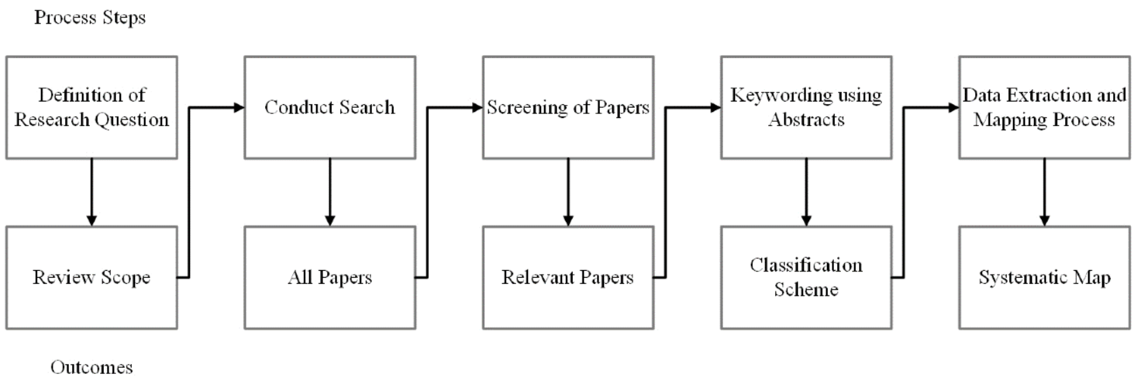

Figure 3 - Systematic Mapping Study Process Steps (source: Yli-Huumo, et al., 2016)

Although the methodology used by Yli-Huumo et al. could be considered adequate, the cumulative number of papers was only forty-one at the end of 2015. Most of the studies had been focused on challenges and limitations. The number of studies has become increasingly numerous ever since. Allegedly, the results would be significantly different if the same research were conducted today.

The authors answered the questions mentioned above as follows:

Q1: A substantial portion of the research in 2016 was concentrated on security and privacy issues. The research on other topics could have been more extensive compared to these issues.

Q2: BCT cannot be limited to cryptocurrencies. Instead, fields of application are various since decentralized public ledgers can be helpful to different sectors. Thus, blockchain technology is attractive for several industries.

Q3: The authors have identified a few significant research gaps. First, research on some technical topics did not exist at that stage. Second, on usability, the study used only a user perspective, not a developer perspective. This limited the options for more applications and solutions. Third, research was conducted in the Bitcoin environment rather than Blockchain. Lastly, only a few publications were in high-quality journals and channels.

Q4: The future research directions for Blockchain needed to be clarified at the time of this paper.

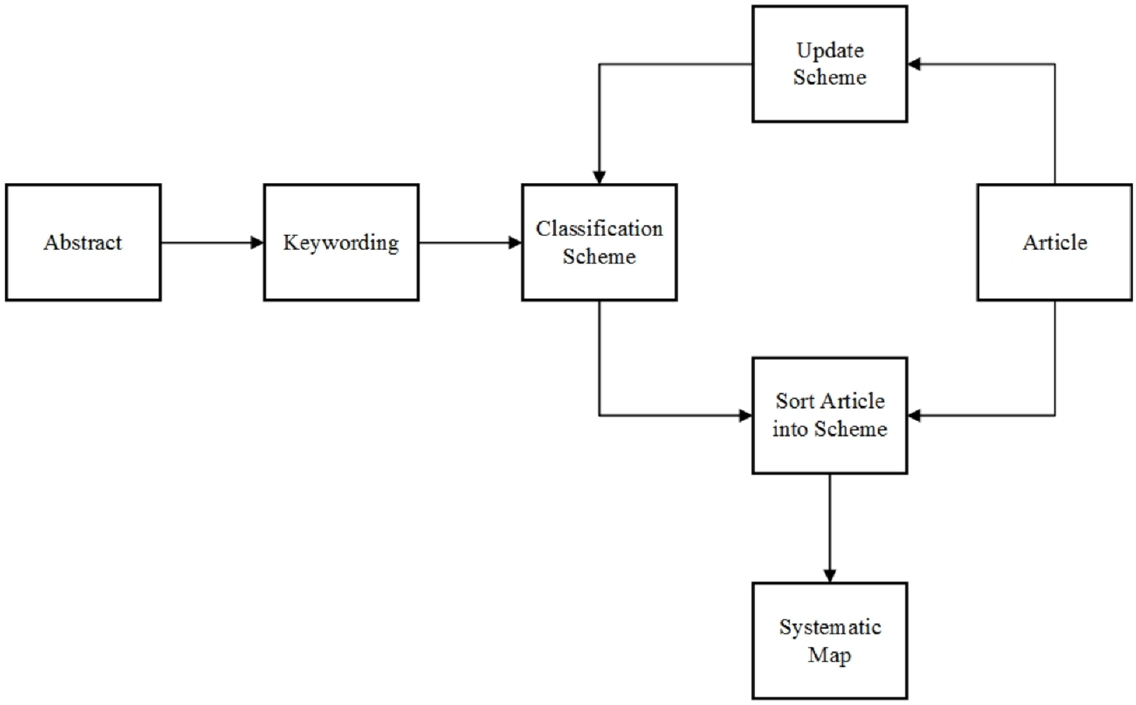

Figure 4 - Systematic Mapping Study Operational Diagram (source: Yli-Huumo, et al., 2016)

Hence, to expand our findings, we adopted a similar approach. For this purpose, we designed our search protocol. Following the standard procedure for systematic literature reviews and mapping studies - with minor changes as applicable – the review scope must be defined.

First, we defined the research questions:

- Question 1: What approaches and methodologies are researchers adopting for reviewing blockchain?
- Question 2: Did the methodology give a consistent contribution to the research on the blockchain?
- Question 3: Is there any gap that needs to be filled?
- Question 4: What are the alternatives that can be used?

Second, we selected a representative group of five multidisciplinary online databases with free or partially free access and significant size. Considering the number of contents available and the search engines' power output has significantly increased, this selection would probably be adequate and effective for our objective.

The selected databases for our work are the following:

- SCOPUS.COM: Elsevier's abstract and citation database that collects about eighty-seven million publications. Scopus was preferred since it is a well-known index covering a wide range of peer-reviewed journals and gives accurate bibliographic information.
- SCILIT.NET: a platform that aggregates scholarly publications. The open-access publisher MDPI (Multidisciplinary Digital Publishing Institute) AG has developed and maintained it. The platform currently collects about 151 million publications.
- CORE.AC.UK: open access content aggregator platform developed by the Knowledge Media Institute based at The Open University, United Kingdom. The collection amounts to 249 million contents.
- BASE-SEARCH.NET: BASE (Bielefeld Academic Search Engine) is a multidisciplinary search engine created by Bielefeld University Library in Bielefeld, Germany, based on free and open-source software. The database includes 315 million contents.
- MYSCIENCEWORK.COM: technology company that promotes easy access to scientific publications and open science. Their comprehensive database includes more than ninety million publications.

After that, we designed a search protocol to select the most appropriate keywords and consider additional filters to eliminate irrelevant content. Choosing the right keywords is essential to avoid misleading searches and ensure that relevant articles are included.

We adopt the approach that Kitchenham and Charters (2007) proposed for successive refinements, which suggests using quality assessment checklists to assess individual studies. This method defines a list of questions and characteristics that an article should comply with to eliminate those articles that apparently fit with the purpose but lack some essential components for the goal of our research.

1.3 Results

The first trial was conducted by adopting the same search protocol used by Yli-Huumo et al. [33]. Thus, we considered all documents that include the word "blockchain" in the title, in the abstract, or as a keyword, for all the databases included in the five search engines previously indicated.

Database	Developer	Size	#Articles
SCOPUS	Elsevier	87M	83,143
SCILIT	MDPI	151M	53,326
CORE	Knowledge Media Institute	249M	40,469
BASE	Bielefeld University Library	315M	75,513
MYSCIENCEWORK	MyScienceWork	90M	10,395

Table 1 - Output of the search protocol (1)

Despite the smallest size, SCOPUS returned the highest number of results. This is in line with what we expected since it has the most powerful software - and very efficient tools to refine the research and analyze the output. Nevertheless, it is a commercial service containing only peer-reviewed and certified documents. These results depend on Elsevier's access to a wider variety (and complexity) of databases and libraries. In terms of the number of articles per year, the number of publications is becoming huge. Figure 5 provides some information on trends and the growth rate of publications. We can observe a constant increase year after year, but the growth rate is slowing down starting from 2021 – with a slight decrease in 2021 for CORE. In 2022, only SCOPUS already overcame the previous year's publications.

year	SCOPUS	SCILIT	CORE	BASE	MY SCIENCE WORK
2008	2	4	5	4	0
2009	0	0	6	0	0
2010	1	0	11	0	0
2011	0	1	9	1	0
2012	1	4	17	0	0
2013	6	4	23	8	0
2014	30	19	104	32	0

2015	83	74	191	120	27
2016	273	322	514	752	138
2017	1245	1399	2036	2966	687
2018	4422	4427	5853	8840	1671
2019	9845	8186	8451	13527	1914
2020	16074	11453	9156	16527	1946
2021	24331	14356	8583	19195	2157
2022	26830	13077	5510	13541	1855
cum.	**83143**	**53326**	**40469**	**75513**	**10395**

Table 2 - Output of the search protocol (2)

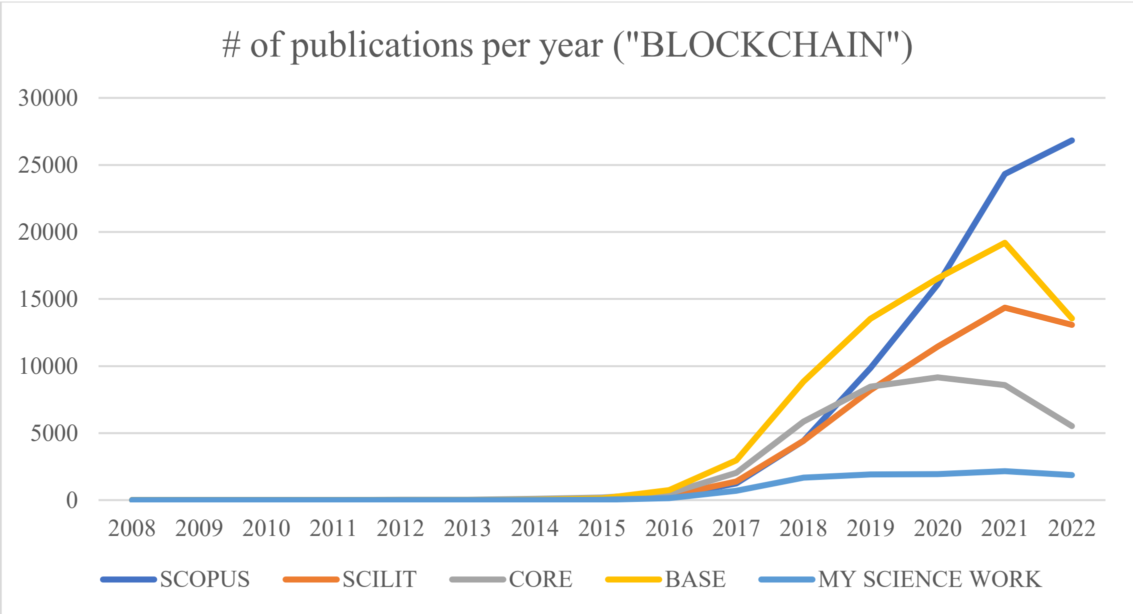

Figure 5 - Number of publications (time series) (1)

SCOPUS provides tools to sort publications by subject area. The sum does not correspond to eighty-three thousand contents since some can be included in more than a single area. However, more than two-thirds of publications can be attributed to the Computer Science subject, while only a tiny portion refers to multidisciplinary contents. It is essential to notice that most of the contents are empirical papers applied to specific areas, and only a small percentage is conceptual.

Moreover, we can note that, excluding the most apparent results (i.e., Computer Science, Engineering, Mathematics), research activity focused on Social Sciences, with a strong preference for Decision Sciences. Surprisingly, Economics and Finance are less than half of Business Management and Accounting and fewer than Energy, Physics, and

Astronomy. The cumulative number of articles concerning Medicine, Health, Pharmacology, and Bio-Chemical matters is significantly high. This will help us to understand the current trends in terms of fields of application. However, they are still a tiny percentage – as expected.

Lastly, we can observe that there are fields where research is still at an early stage, for example, Arts and Humanities, Earth and Planetary Sciences, and Agriculture.

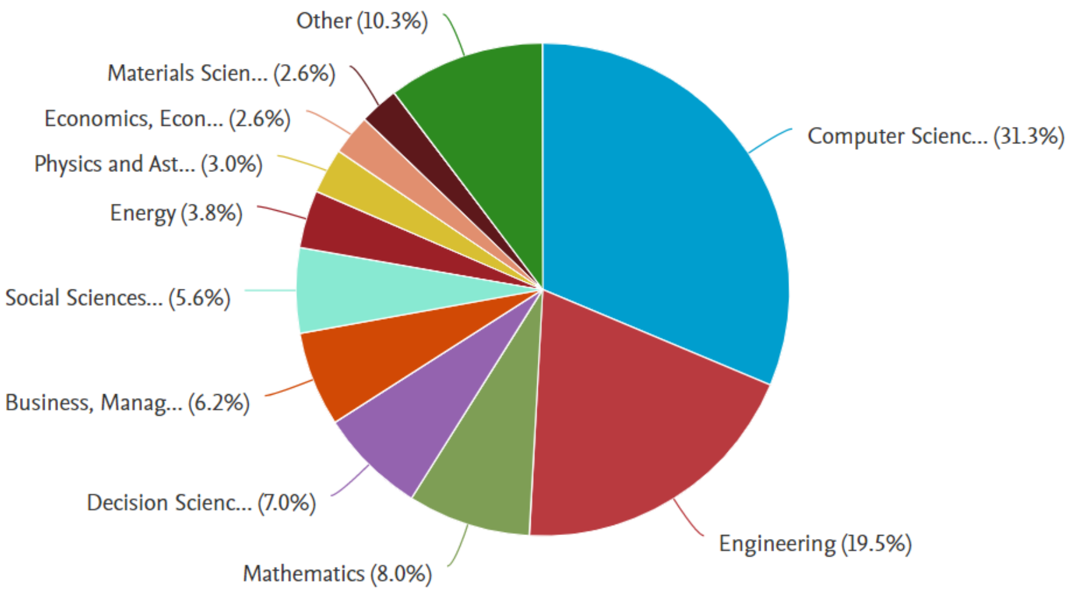

Figure 6 – Distribution of studies by fields of research (source: SCOPUS.COM)

Subject	**# Of articles**
Computer Science	57037
Engineering	35576
Mathematics	14631
Decision Sciences	12763
Business Management and Accounting	11317
Social Sciences	10175
Energy	6880
Physics and Astronomy	5441
Economics, Econometrics, and Finance	4788
Material Science	4672
Environmental Science	4412
Medicine	3934

Biochemistry and Biology	1986
Chemistry	1523
Chemical Engineering	1230
Agriculture	1153
Earth and Planetary Sciences	887
Arts and Humanities	761
Multidisciplinary	701
Psychology	669
Neuroscience	465
Health	404
Immunology	212
Pharmacology	203
Nursing	139
Veterinary	32
Dentistry	11

Table 3 - Number of publications by sector

Since our research aims to review and structure the state-of-the-art research methodology applied to the blockchain to understand which approach could be the most suitable and considering that the number of results was excessively high and it would be incredibly challenging to read and analyze all publications returned by the initial search protocol – it would be an enormous task - we defined a new algorithm.

We conducted a new search, filtering the first trial by including more keywords and parameters. For this purpose, we refined our protocol by adding new filters for all five search engines: [1] "research methodology" as a combined sub-keyword with "blockchain"; [2] articles available in open access, [3] in English[6], [4] between 2008 to 2022.

Finally, the number of articles significantly decreased (Table 4). Also, the search protocol did not detect any content till 2014. The returned results became the new running

[6] Filters for SCOPUS search engine: (blockchain) AND ("RESEARCH METHODOLOGY") AND (EXCLUDE (OA , "all")) AND (INCLUDE (PUBYEAR , 2008) OR INCLUDE (PUBYEAR , 2009) OR INCLUDE (PUBYEAR , 2010) OR INCLUDE (PUBYEAR , 2011) OR INCLUDE (PUBYEAR , 2012) OR INCLUDE (PUBYEAR , 2013) OR INCLUDE (PUBYEAR , 2014) OR INCLUDE (PUBYEAR,2015) OR INCLUDE (PUBYEAR , 2016) OR INCLUDE (PUBYEAR , 2017) OR INCLUDE (PUBYEAR , 2018) OR INCLUDE (PUBYEAR , 2019) OR INCLUDE (PUBYEAR , 2020) OR INCLUDE (PUBYEAR , 2021) OR INCLUDE (PUBYEAR , 2022)) AND (LIMIT-TO (LANGUAGE , "English"))

selection, and we finally assessed which contents could be included in our analysis. Even in this case, we observe a gradual decrease in growth rate in 2022, although it is not evident, as in the previous attempt, that the total number at the end of the year would be lower than in 2021 (Figure 7).

year	**SCOPUS**	**SCILIT**	**CORE**	**BASE**	**MY SCIENCE WORK**
2015	0	0	0	1	0
2016	1	0	0	1	0
2017	8	0	12	3	2
2018	20	3	130	9	14
2019	53	3	13	9	21
2020	87	11	9	17	13
2021	194	14	1	27	25
2022	257	15	0	14	24
cum.	**620**	**46**	**165**	**81**	**99**

Table 4 - Output of the search protocol (3)

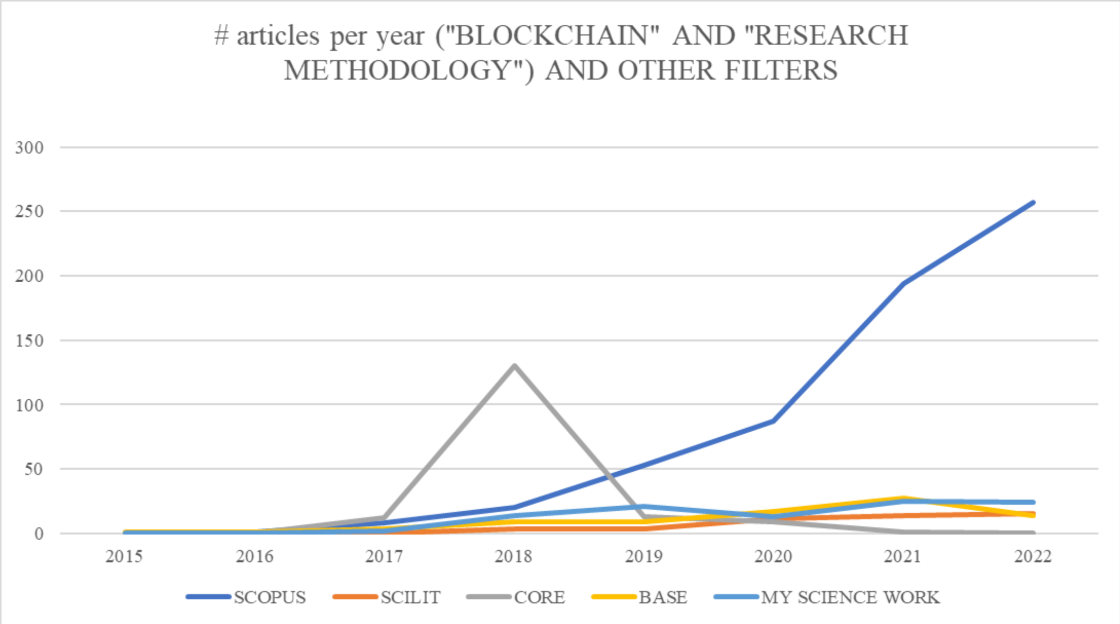

Figure 7 - Number of publications (time series) (2)

To eliminate those articles with a different purpose than an in-depth overview of research methodology or systematic reviews, we followed the approach proposed by Kitchenham and Charters [35], which suggests using quality assessment checklists to assess individual studies. We proceeded with the refinement stages by reading titles and abstracts of the whole list. The eligibility criteria adopted to determine the quality of our results were the following:

1. Are the research aims clearly stated?
2. Did the research achieve its objectives?
3. Are the databases, search protocols, and data collection methods defined?
4. Are the research questions answered?
5. How do results compare with previous literature?
6. Do the findings expand the literature?
7. How do the results add to our knowledge?

Not surprisingly, most publications were not reviews or research methodology proposals, and some were literature reviews focused on a single field of application without detailed information on research methodology. By excluding them and adding more content by bibliographic trail search and reference lists, we collected twenty-one eligible papers (of which six have been traced by bibliographic trail search and reference lists).

Here are preliminary findings and tables that summarize the results.

#	**Author**	**Year**	**Research Methodology**	**# Of contents included**
1	Yli-Huumo et al.	2016	Systematic mapping study	41
2	Leon Zhao et al.	2016	Overview	90
3	Risius and Spohrer	2017	Systematic literature review	69
4	Brandao et al.	2018	Systematic literature review	190
5	Andrian et al.	2018	Systematic literature review	35
6	Milosz et al.	2018	Systematic literature review	432
7	Xu et al.	2019	Systematic literature review	119
8	Tasca and Tessone	2019	Taxonomy	ND
9	Zhou et al.	2019	Scientometric review	2792
10	Treiblmaier	2019	Recommendations	ND
11	Meiriño et al.	2019	Systematic literature review	102
12	Casino et al.	2019	Systematic literature review	314
13	Firdaus et al.	2019	Bibliometric analysis	1119
14	Lyu et al.	2020	Scientometric review	1056
15	Frizzo-Barker et al.	2020	Systematic literature review	155
16	Bharadwaj et al.	2020	Systematic mapping study	604
17	Alkhudary et al.	2020	Systematic literature review	47
18	Lim et al.	2021	Systematic literature review	106

19	Alsmadi et al.	2022	Bibliometric analysis	1225
20	Garcia-Corral et al.	2022	Bibliometric analysis	1419
21	AlShamsi et al.	2022	Systematic literature review	684

Table 5 – Selected papers (1)

The most frequent methodology is the Systematic Literature review (11), followed by Bibliometric analysis (3), Systematic Mapping Study (2), and Scientometric Reviews (2). Other methodologies have different objectives, but they can be helpful for the comprehension of the state-of-the-art. Regarding keywords, the most frequent was “blockchain”, as we did in our first attempt and according to Yli-Huumo et al. [33].

year	# Of articles
2016	2
2017	1
2018	3
2019	7
2020	4
2021	1
2022	3

RESEARCH METHODOLOGY:
Systematic Mapping Study: 2
Systematic Literature Review: 11
Scientometric review: 2
Taxonomy: 1
Overview: 1
Bibliometric analysis: 3
Recommendations: 1

Table 6 - Distribution of studies by year and methodology

#	Author	Databases	Other tools
1	Yli-Huumo et al.	IEEE Xplore, ACM Digital Library, Springer Link, ScienceDirect, Ebsco, PLoS One	
2	Leon Zhao et al.	Web of Science, SSRN	
3	Risius and Spohrer	Web of Science, IEEE Xplore, the AIS Electronic Library, ScienceDirect, SSRN	
4	Brandao et al.	IEEE Xplore, Springer Link, ScienceDirect, the YMCA, Google Scholar	
5	Andrian et al.	IEEE Xplore, Springer Link, Scopus, ScienceDirect	
6	Milosz et al.	Web of Science, BIOSIS Citation Index, Current Contents Connect, Data Citation Index, Derwent Innovations Index, KCI-Korean Journal Database, MEDLINE, Russian Science Citation Index	
7	Xu et al.	Web of Science, SCI-E, SSCI, AHCI, ESCI	CiteSpace
8	Tasca and Tessone	(none)	

9	Zhou et al.	Web of Science	CiteSpace
10	Treiblmaier	EBSCOhost, ScienceDirect, Google Scholar, ResearchGate	
11	Meiriño et al.	SCOPUS	
12	Casino et al.	SCOPUS	
13	Firdaus et al.	SCOPUS	R
13	Lyu et al.	SCI-E, SCII	
14	Frizzo-Barker et al.	Business Source Complete, SpringerLink, Web of Science	NVivo12
15	Bharadwaj et al.	IEEE Xplore, ACM Digital Journal, SpringerOpen, ScienceDirect	
16	Alkhudary et al.	ProQuest, SCOPUS, Business Source Ultimate	
18	Lim et al.	Web of Science Core Collection	
19	Alsmadi et al.	SCOPUS	VOSviewer
20	Garcia-Corral et al.	SCOPUS, Web of Science	VOSviewer, R, Tableau
21	AlShamsi et al.	Emerald, IEEE, ScienceDirect, Springer, MDPI, Google Scholar	

Table 7 – Selected papers (2)

#	**Author**	**Main Topics**	**Keywords**
1	Yli-Huumo et al.	Global	"Blockchain"
2	Leon Zhao et al.	Business innovation	
3	Risius and Spohrer	Global	"Blockchain" OR "Block chain"
4	Brandao et al.	Smart Places	"Blockchain"
5	Andrian et al.	Applications	"Blockchain"
6	Milosz et al.	Information security	“Blockchain”
7	Xu et al.	Business and Economics	"Blockchain"
8	Tasca and Tessone	Classification	
9	Zhou et al.	Global	"Blockchain" OR "distributed ledger" OR "smart contract" OR "bitcoin" OR "ethereum" OR "hyperledger fabric"
10	Treiblmaier	Recommendations for Case Studies	“blockchain” OR “Distributed Ledger Technology” in any

			combination with “case study”, OR “use case”, OR “case”,
11	Meiriño et al.	Applications	"Blockchain" AND ["Cryptocurrency" OR "Cryptocurrencies"] OR ["Smart contract"] OR ["IoT" OR "Internet of Things"] OR ["Smart Property"] OR ["Digital content distribution"]
12	Casino et al.	Applications	"Blockchain" OR ["Blockchain" AND "Application"]
13	Firdaus et al.	Global	“Blockchain”
14	Lyu et al.	Global	"Blockchain" OR "Block chain" OR "block-chain"
15	Frizzo-Barker et al.	Business and Economics	"Blockchain"
16	Bharadwaj et al.	Global	"Blockchain"
17	Alkhudary et al.	General management; Economics	"Blockchain" OR "block chain" OR "block and chain" OR "consortium chain" OR "smart contract" OR "distributed ledger" OR "Hyperledger" OR "decentralized consensus"
18	Lim et al.	Supply chain	“blockchain” AND [“supply chain” OR “transport” OR “logistics” OR “cross-border trade” OR “manufacturing”]
19	Alsmadi et al.	Cryptocurrencies	Various
20	Garcia-Corral et al.	Cryptocurrencies	“blockchain” OR “Bitcoin” OR “Ethereum”
21	AlShamsi et al.	Applications	“Blockchain” AND (“Adoption” OR “Acceptance” OR “Use” OR “Intention to use” OR “continued use” OR “Continuous intention”)

Table 8 – Selected papers (3)

1.4 Relevant Findings from the Survey

Leon Zhao et al. [4] offered an overview of blockchain business innovations and research opportunities. Considering the strictness of the verification process, efficiency is among the key issues for blockchain that can limit its adoption. Using the Web of Science and SSRN database, they found that the number of articles increased hugely – from zero before 2014 to 90 academic papers in 2016. Three categories of studies should be considered by research: conceptual, prescriptive, and descriptive. At that stage, the conceptual level was the main focus of academic literature, while prescriptive and descriptive analyses were lacking. They noticed a gap in the research on related theoretical issues and impact analyses that will guide blockchain ventures toward dramatic impacts on the economy, society, governance, and others.

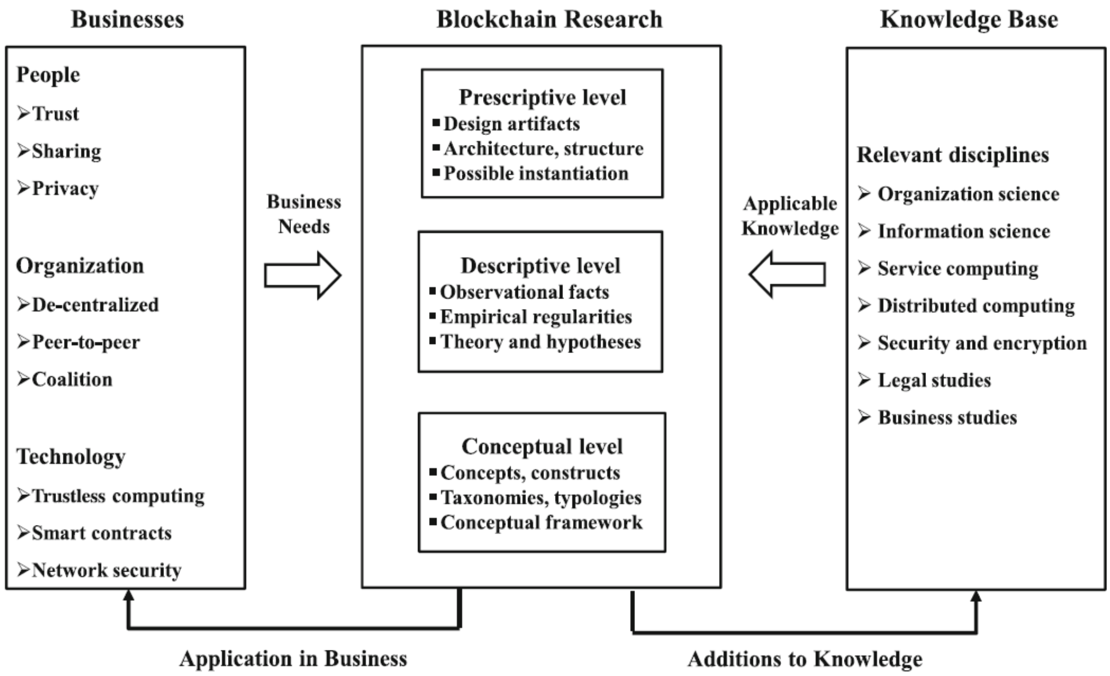

Figure 8 - Illustration of the Blockchain Research Landscape (source: Leon Zhao, et al., 2016)

Risius and Spohrer [36] argued that application-oriented contributions to blockchain research must be more extensive but selective about topics. They adapted Morris' five-step framework, previously used in social media and business transformation to blockchain technology, to systematically classify findings and, most importantly, suggest new research topics beyond the current subjects. The databases considered were SpringerLink (1716 articles), IEEE Xplore (94 articles), and ScienceDirect (1383 articles). After the selection process, the final set included sixty-nine papers from the academic literature. The contribution of their work needs to be considered in light of its limitation. Research questions were built in cooperation with blockchain developers. Nonetheless, their work aimed to study and develop a framework for blockchain technology research without restrictions on fields and areas. One of the main results of this study refers to the opportunities for multidisciplinary research and collaborations that could improve knowledge and understanding of this technology, especially regarding value creation.

Brandão et al. [37] proposed to update the work by Yli-Huumo et al. [33], using the same approach and keywords but considering different search engines. They included in their search protocol the following databases: IEEE Xplore, Springer Link, ScienceDirect, the YMCA, and the Google Scholar catalog. As expected, the results showed an increase in the number and topics, with a total of 190 publications – of which 100 in 2017. Their review focused on characteristics and features of blockchain technology (security, trust, privacy, anonymity, scalability), potential blockchain applications (cryptocurrencies, Internet of Things, Finance, Government, Smart contracts, Smart cities, Business, Health), and alternative options to Bitcoin consensus mechanism (in particular, Ethereum). According to their conclusions, platforms adopting blockchain technologies were limited and inefficient. The capability could increase only after observing a global distribution of these platforms.

A systematic literature review has been provided by Andrian et al. [5]. They collected a total of 710 articles found in four different databases: IEEE Xplore (449), SpringerLink (22), SCOPUS (179), and ScienceDirect (60). The main findings were similar to the previous research activity. More application fields are emerging, which would require a higher differentiation since implementation fields were divided only into financial and non-financial. Blockchain cannot be considered applicable only to cryptocurrencies and financial instruments, and future research should better address this issue.

Milosz and Moniusko [38] presented the systematic literature review as a methodology for the emerging technologies analysis, constating in the following steps: searching for articles in scientific databases using keywords related to the specific subject or theme, deleting non-related papers, refining the area and search criteria and estimate the statistics and analytics of the occurrence of the topics. Studying the growth rate of the occurrence in articles and papers on a given subject can help identify if a rapid development is happening. Finally, the authors presented a case study on information technology and its sharp increase since blockchain technology fits ideally, given its ability to enhance information security and data protection. Research on information security has grown significantly, looking at the number of academic articles in 2017 and 2018. They included eighty-nine publications in the year 2016 and 343 in 2017.

A systemic review has also been provided by Xu, Chen, and Kou [3]. They used the already mentioned methodology to analyze 756 articles in WOS Core Collection by using "blockchain" as the unique keyword. Their search was conducted on four WOS databases: Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, and Emerging Sources Citation Index. The more common keywords were bitcoin, smart contract, and cryptocurrency. It shows that Computer Science is the most frequent subject area, followed by Engineering, Telecommunications, and Business and Economics. In the research of Business and Economics, some key points are highlighted in the literature, such as the most referenced papers, the most prolific countries, and the most frequent keywords. The five most common research topics were: "economic benefit," "blockchain technology," "initial coin offerings," "fintech revolution," and "sharing economy".

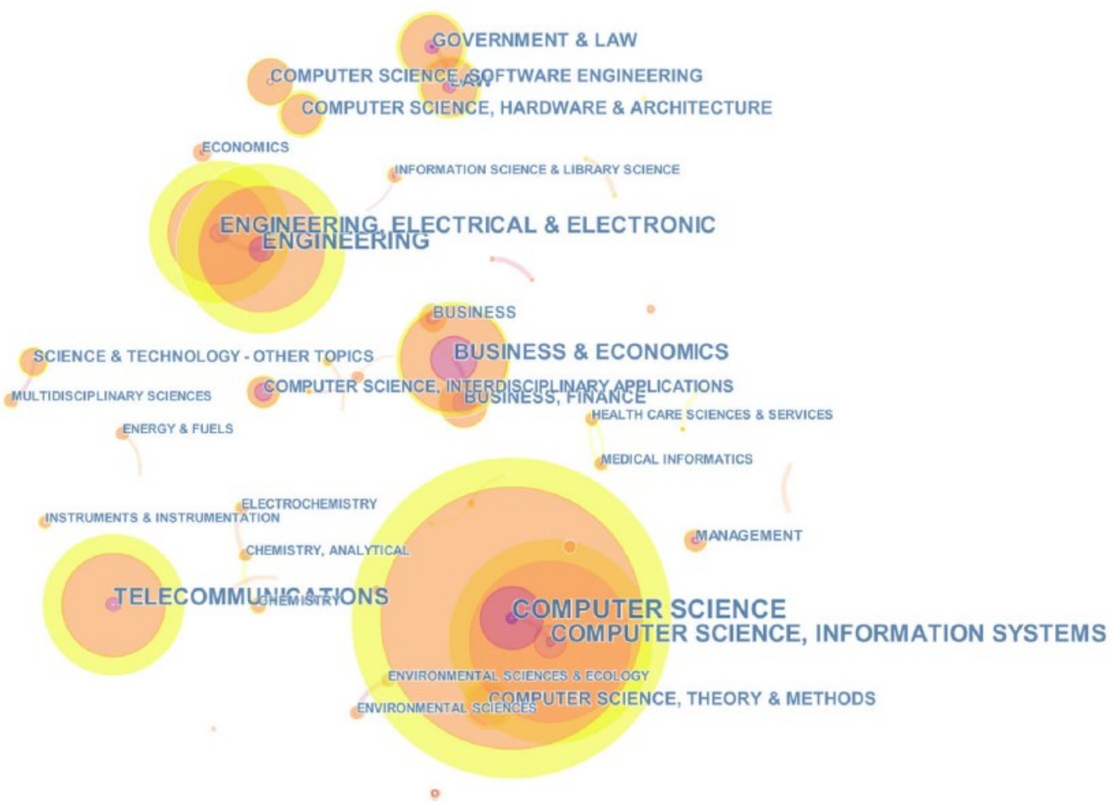

Figure 9 - Disciplines in blockchain (source: Xu, et al., 2019)

A different contribution has been provided by Tasca and Tessone [30]. They reasonably argue that we are living in a fermentation phase of the development of this new technology – according to the Technology Life Cycle theory- characterized by uncertainty on the future paths that the evolution of blockchain could take. In fact, thousands of ongoing projects involve blockchain, some of which propose alternative architectural configurations. However, all of them can be included in the family of distributed ledger technologies. Although this aspect can be considered a fundamental step to achieving a widespread diffusion of these technologies, heterogeneity could face problems preventing a consensus-based diffusion and stimulation of innovation.

The research conducted by Tasca and Tessone helps us to detect and classify blockchain components, frameworks, and layouts. For example, Bitcoin is a peer-validated cryptocurrency combining existing technologies (distributed ledgers, public-key encryption, Merkle tree hashing, and consensus protocols). As they argued, blockchain has been considered a disruptive technology. Bitcoin uses only a few recent innovations since it includes features and technicalities presented and analyzed decades before, as mentioned in section 1.1. In this sense, we can find hashes in cryptography for information security in the 1950s, the proposal of Merkle's tree by Ralph C. Merkle in the 1970s, and hash utilization for a secure login in Lamport, et al. [39]. More innovations were introduced in the 1990s, including a very first proposal of a cryptocurrency. Nakamoto's paper has been a game changer because of the elaboration of a cryptocurrency that uses the Proof-of-Work concept.

There is no denying that blockchain technologies will be one of the most used innovations in the future of our society. Thus, we must begin discussing and identifying standards for BCT frameworks and technical reference models.

Between others, we can include the following issues:

- Absence of consistency in laws, policies, and regulations of BCT.
- Ambiguity in the application of rules.
- Unpredictability for the impact on the market labor.
- Decreased accuracy of academic research.
- Inhibition of the adoption of blockchain-based solutions.
- Additional complexity for understanding this new infrastructure, reducing the willingness to adopt them.

Uncertainty, combined with heterogeneity and variations in designs and frameworks, is slowing down a uniform adoption of blockchains since they prevent a proper understanding of this phenomenon and cause an increase in research and implementation costs. Also, we can see a need for measurement methodologies to compare quality and efficiency, posing additional problems that must be addressed. In the long term, the absence of standards will carry privacy, security, governance, and transparency risks – and this is already true regarding cybercrimes and illegal international trade.

For a general understanding of the discussion, Tasca and Tessone proposed a blockchain taxonomy, starting from a definition of the word "Taxonomy": "*Taxonomy comes from the term "taxon", which means a group of organisms. In our case, taxonomy encompasses the identification, description, nomenclature, and hierarchical classification of blockchain components. This differs from an ontology that studies the types, properties, and interrelationships of the components and events that characterize a blockchain system."*

The methodological approach they used is composed of the following steps:

(1) Analysis across blockchains. Compare blockchains across different domains and clarify their terms and concepts to sort out ambiguities. Review the existing technologies and use an online database of standard blockchain terms to avoid confusion. Identify the main components of blockchains and how they relate to each other in different applications: digital currencies, application stacks, asset registry technologies, and asset-centric technologies.

(2) Framework setting. Create and fill a hierarchical taxonomy (a tree structure of classifications) with blockchains' main, sub, and sub-subcomponents.

(3) Layout categorization. Introduce and compare different layouts for the lowest-level components in the taxonomy. The authors limit the study to a few layouts for each sub or sub-subcomponent, as technology is evolving fast.

The result is a universal blockchain taxonomy tree that groups the significant *"components in a hierarchical structure and identifies their functional relation and possible design patterns."*

The authors concluded the analysis by saying their work shed light on interoperability and the rapid increase in diverse platforms, exacerbating the need for blockchain standards. Since development requires several years and trials, this taxonomy is helpful to support future research that aims at reducing complexity and heterogeneity. They did not insist on the need for a set of standards. Their taxonomy can be considered a first proposal.

This aligns with Sultan et al. [21], which offered a conceptual overview of blockchains by describing their underlying technological functions and discussing their potential applications. Blockchain innovation sharply involves various sectors and industries beyond financial transactions, and many use cases are already available. Considering this, they offered a connotative definition that describes the key features of blockchain technology – related or not to Bitcoin.

A different approach has been proposed by Zhou et al. [40]. Using the Web of Science Core Database and a wider variety of keywords ("blockchain", "distributed ledger", "smart contract", "bitcoin", "Ethereum", and "Hyperledger fabric"), they conducted a Scientometric review getting a total of 1951 results. Then, they added to the list all articles that cited at least one of the 1951 records, obtaining 2870 records after merges and deduplication. CiteSpace was used to form an overview network. CiteSpace's algorithms include the K-means algorithm and algorithm that are based on convex spherical sample space. The main advantage is the flexibility and robustness of spectral clustering. In addition, they adopted LDA as a Probabilistic Generative Model that considers the content of the text. According to their search, the number of papers citing blockchain is exponentially increasing.

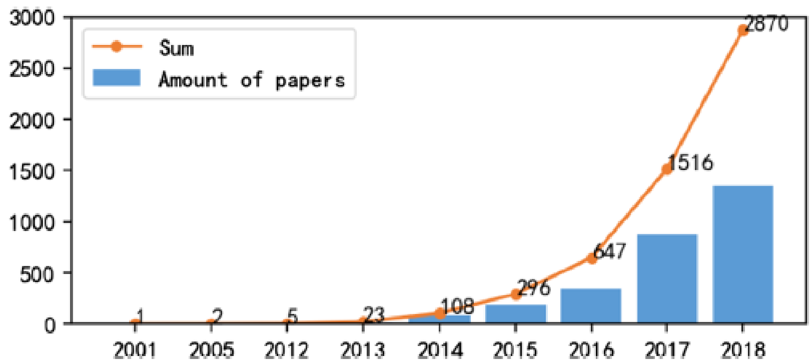

Figure 10 - Literature published in the blockchain field from 2001 to 2018 (source: Zhou, et al., 2019)

The following chart better describes the contribution that research activity provides to this new field and the variety of areas of applications. Each node corresponds to one of 10,000 journals on the WOS index. Different arcs represent citations between studies. The left side nodes include journals where the citing literature is located (main topics: computers, mathematics, economics), while the right side indicates a broader distribution of journals and citations.

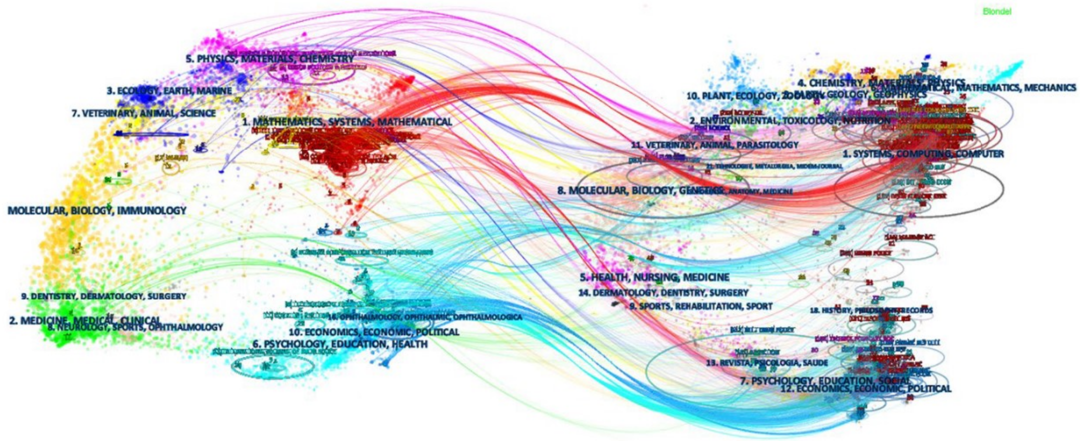

Figure 11 - Dual-map overlay of citing literature and cited literature (source: Zhou, et al., 2019)

The authors also described a landscape of the co-citation network based on papers published between 2001 and 2018. According to them, the main themes of the seventy thousand references include Bitcoin, Framework, Economy, Application, Silk Road (website), Fintech, Social governance, Data preservation, and Income. In conclusion, future research should focus on the empirical impact of digital currencies, risk issues on banking and financial services, the relationship between digital currency and Internet public opinion, improvement of blockchain technology architecture, and integration with other recent technologies.

A different approach has been used by Treiblmaier [22]. In his article, he tried to offer some guidelines and suggestions for future works and research on blockchain technology. This approach could seem less robust at first sight. It provides relevant hints to help researchers design and structure case studies to create credibility, recognizability, and, most importantly, added value. Case study research design varies according to the state-of-the-art of research and technology development. Thus, the author conducted a systematic literature review to identify case studies on blockchain technology. The search protocol consisted of performing a database search using the keywords “blockchain” OR “Distributed Ledger Technology”, in any combination with “case study”, OR “use case”, OR “case”, using the following databases: Business Source Premier from EBSCOhost, ScienceDirect, Google Scholar, and ResearchGate. To select existing blockchain case studies, these relevant criteria were adopted: (a) case study about a prototype or an application, (b) solutions for a specific company, (c) solution for a specific industry. At the end of the selection process, twenty-one articles were retrieved. Here follows a table synthesizing all noteworthy features and theoretical contributions that case studies can give to academia and industry.

	No Theory First (NTF)	Gaps and Holes (GAH)	Social Construction of Reality (SCR)	Anomalies (ANO)
Motivation	Preliminary variables and constructs, no relationships	Existing Theory	Curiosity in the case	Curiosity, contradictions
Data	Theoretical sampling	Purposive sampling	Purposive sampling	Theoretical sampling
Analysis	Constructs and relationships	Pattern-matching, analytic, generalization	Categorical Aggregation	Structuration, reconstruction of theory
Methods	Case descriptions, interviews, documents and observations	Case descriptions, interviews, documents and observations	Learning from the case, rich descriptions	Observation, interviews, dialogue between observer and participants
Theory focus	Building theory	Developing theory, testing theory	Building theory	Testing theory

Table 9 - Case study research designs and their theoretical contributions (source: Treiblmaier, H., 2019)

According to Treiblmaier, blockchain case studies research needed to be more cohesive and consistent. Only two case studies were supported by a theoretical conceptualization. However, all case studies tried to provide an overview of fields of interest. In its conclusion, the author recommended that case studies follow some steps:

- clarify the reasons for applying blockchain in their research problem.
- select the technology that best suits their needs and objectives.
- determine which features of blockchain technology are valuable and essential for their study.
- recognize the potential difficulties and consequences that may arise from using blockchain.
- justify the choice of that particular case study as an example of their research question.
- describe the steps and procedures they followed in conducting their research.
- provide appropriate analysis and interpretation of the results.
- provide a critical evaluation of the strengths and weaknesses of their research.

- relate the findings to a broader research field and suggest directions for future research.

Designing a case study requires following some specific steps so that all elements involved are taken into account. First of all, it must be determined which phenomenon will be analyzed. The description of the case study should outline the design, motivation, data sources, and context. In essence, the goal is to define the basic structure and objectives of the Project and how these influence the selection of the methodology used. Once we understand what we will address, we can proceed with describing the relevant features of the blockchain and how they contribute to providing a solution to the problem already specified. Only after we have given a justification for our method can we choose the most practical approach. It depends on the objective. On the one hand, if we want to give rise to a theoretical description, we need to establish on what theoretical basis our analysis lies and subsequently identify to which similar situations our case can be applied. On the other hand, if we want to propose a more specific and practical application, we must follow some practical recommendations related to tracking and tracing the design, development, and implementation process.

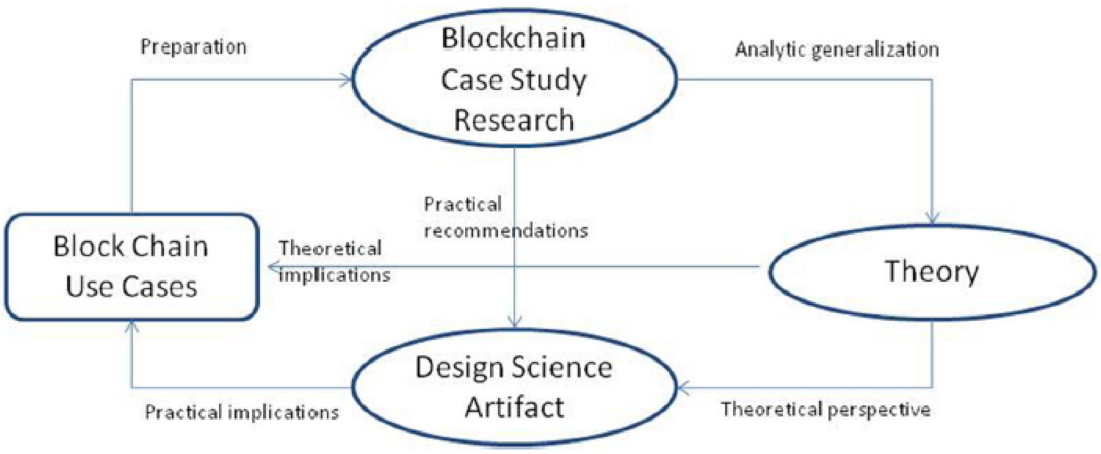

Figure 12 - A framework for blockchain case study research (source: Treiblmaier, 2019)

Taking inspiration from Treiblmaier's checklist, which is based on recommendations for systematic reviews from Moher et al. [41], here follows a proposal for a simplified table that lists the main steps to be considered to design a case study on blockchain technology properly. In summary, the researcher is asked to define a rationale for the need for blockchain adoption, discuss the blockchain architecture and its relevant characteristics, the main challenges and their impact on the outcome, justify the selection of the case study, present the results and a critical assessment, and finally proposing application to a broader context to strengthen the enabling environment for blockchain implementation.

Topic	**Content**
Goal and Rationale	Description of goals and their relevance, and rationale for the use of case study
Blockchain Rationale	The rationale for adopting Blockchain
Blockchain Description	Description of Blockchain technology and characteristics being used
Justification	Explanation of the methodology
Sources and Data Collection	Description of sources and data collection process
Variables description	Description of variables and their relationships and models that might be used
Results	Presentation of detailed results
Challenges and Limitations	Description of challenges and limitations and their impact on results
Main Findings	Summary of the main findings, assessment of the validity of the study, and differences with the original goals
Conclusions and Implications	A general interpretation of results and implications for future research

Table 10 - Case study checklist (adaptation of Treiblmaier's checklist, 2019)

In Meiriño et al. [42], a systematic literature review has been conducted to serve as a bibliographic reference for future research on potential fields of application. They selected 102 articles from sixty journals through a search on the SCOPUS database, using different search protocols and keywords and in two different timeframes.

The systematic literature search adopted by Casino et al. [8] returned 314 contents, of which 260 articles and fifty-four reports. The following chart describes the strategy and the outcome of each stage of the search protocol:

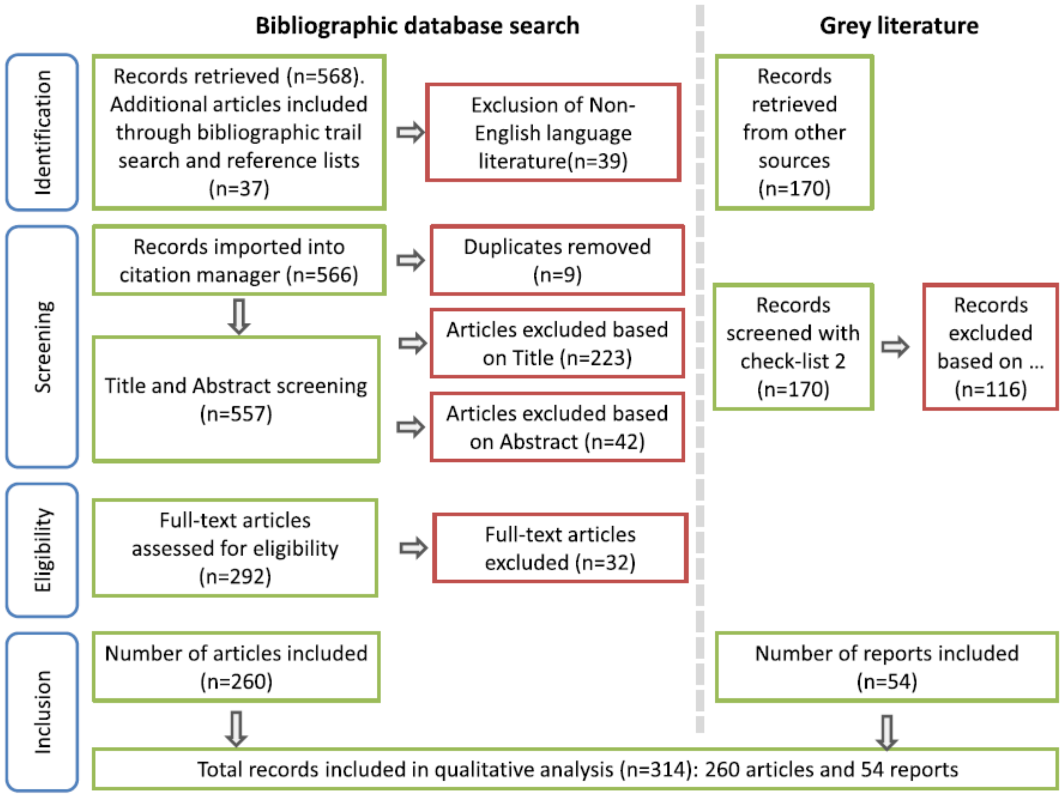

Figure 13 - Flowchart of the search strategy (source: Casino, et al., 2019)

Although the methodology lacks consistency and many articles were added, bibliographic trail search and reference lists (snowball effect), the description of blockchain applications was surprisingly detailed. The authors posed several challenges and open issues that need to be addressed from a technical point of view: suitability, latency and scalability, sustainability and energy consumption, quantum resilience, interoperability, privacy, and security solutions, and the role of big data and artificial intelligence.

Bibliometric analysis has been proposed by Firdaus et al. [29]. The study analyzed more than 1000 articles on the SCOPUS database and helped address the following findings: (i) interest in the blockchain would increase in the future; (ii) the healthcare sector is among the most promising for blockchain applications; (iii) most of the publications comes from USA, followed by China and Germany, but researchers from Switzerland and Singapore have also provided relevant contributions in terms of citations; (iv) multidisciplinary approaches and multi-country collaborations increase publications; (v) privacy, digital storage, security, big data, and distributed database are the most common field of research. The authors also provided a helpful classification of different consensus algorithms.

Lyu et al. [9] used the bibliometrics method mainly to investigate the research trends. This paper conducted a bibliometric analysis of 1,056 block-chain documents until 2018 from the WoS database targeting the Science Citation Index Extension (SCI-E) and Social Science Citation Index (SSCI).

The research results show that the blockchain is an emerging field, starting in 2013 and confirming global publication trends. Blockchain mainly involves computer science disciplines, including theory and methods, information systems, software, hardware, and artificial intelligence. Research in engineering primarily focuses on electrical and electronic, energy, etc., and many subfields are under electronic communication. The outer layer of blockchain research is also applied to business and economics, finance, and other disciplines. Computer science is the earliest discipline of blockchain research. Later, with the continuous development of blockchain technology, it continued to extend to other domains, transitioning gradually from theoretical research to application realization as time went by. The analysis of the author's cooperation network shows that scholars in the field of blockchain have general research cooperation. Research cooperation exists in small groups in the current stage of blockchain research. Each group usually has several core authors and other less critical group members. Most of the authors in this small group are geographically similar or have the same nationality. The analysis of the national cooperation network shows that the blockchain literature published by the USA, P.R. China, and England overpass 50% of the world's total literature in this area. They are the leading countries dedicated to research and global development in the blockchain. The institutional cooperation network shows that most of the international high-yield institutions of blockchain papers are colleges and universities. In addition, a few research institutes are also high-yield institutions, and there is no close relationship between the institutions. Their cooperation mechanism is also geographically centered, and a significant and frequent cross-regional cooperation network is not yet. Statistical and cluster analysis of author keywords shows that the research on the blockchain is mainly focused on digital currency, smart contracts, and the Internet of Things. We can observe that there is space to expand research on blockchain technology in various disciplines. Also, researchers should seek cooperation and complementarity among scientific fields, technologies, and institutions.

In Frizzo-Barker, et al. [10], who conducted a scholarly systematic literature review and analyzed 155 papers, we have exciting findings on the characteristics of studies. Most were conceptual (83%), and only 17% were empirical. Despite this, the percentage of empirical studies is growing yearly (0% in 2015, 11% in 2016, 16% in 2018, and 19% in 2018). This is in line with what we expect in new fields of research and innovation. About 63% were exploratory studies, followed by the theoretical framework (14%) and case studies (12%). Case studies mainly focused on cryptocurrencies, fintech, and data protection. However, according to the authors, many publications did not represent advanced blockchain research but only preliminary studies.

A second systematic mapping study has been conducted by Bharadwaj et al. [7]. The research questions were the following:

RQ1: How have publication amount, frequency, and research topics changed?

RQ2: What are the use cases of blockchain technology?

RQ3: What are the areas of current research in blockchain?

RQ4: How is blockchain research distributed geographically?

RQ5: What is the future research direction for blockchain?

The sources were IEEE Explore, ACM Digital Journal, SpringerOpen, and ScienceDirect, and the keyword was "blockchain". Results are pretty similar to our research and included 604 articles and contents. In particular, the authors noted that a study conducted at separate times could lead to different results, which is a clue of how this field of research is fermenting.

In Alkhudary et al. [6], we can find a systematic literature review of blockchain applications in general management and economics. They used Thomson Reuters and Scimago Journal and Country Rank as search engines, with the following search protocol: ("blockchain OR blockchains OR "block chain" OR "block and chain" OR "consortium chain" OR "smart contract" OR "distributed ledger" OR Hyperledger OR "decentralized consensus"). The time frame selected includes years from 2009 to 2019. The search returned forty-seven articles, mostly on computing engineering. The authors built a qualitative meta-synthesis analysis of the literature focusing on three clusters: law, economy, and innovation. Papers were distributed among five groups: conceptual (35 contents), case study (5), modeling (3), questionnaire (2), and systematic review (2). The authors aimed that: blockchain is linked to ownership registration (law cluster), financial services and cryptocurrencies are still the main topics, and a critical transformation in the currency system is occurring (economic cluster); blockchain is forcing organizations to evaluate new business models (innovation cluster).

Lim et al. [43] focused on supply chain management implications. They conducted a systematic literature review on Web of Science, SCOPUS, and Google

Scholar, using the following keywords: “blockchain”, “Supply chain”, “transport”, “logistics”, “cross-border trade”, and “manufacturing”. After the content screening, the review included 106 valuable articles. The utmost quality of this paper is the detailed description of results and classification of articles based on research methodologies, objectives, and theoretical/empirical support that they have. The authors also provided insight into sectors and fields of discussion. Most of them were conceptual (31 articles), the second largest research methodology classification is “empirical” (28 articles, of which nineteen were qualitative and nine quantitative), while twenty-three articles focused and system implementation. Thirty-five articles used a theoretical approach, and thirty-three articles used quantitative methods to test the effectiveness of blockchain.

Alsmadi et al. [44] provided a bibliometric analysis of cryptocurrencies. They investigated the SCOPUS database, and the research returned 1225 contents between 2016 and 2021. The citation analysis showed an increasing collaboration between authors and countries, with USA and UK as the epicenters of literature on cryptocurrency. The number of articles published by financial and economics publishers was higher than expected, contradicting our results on main topics. However, this can be explained by the study focusing on cryptocurrencies rather than blockchain.

Garcia-Corral et al. [45] conducted a bibliometric review on the same topic (cryptocurrencies) on SCOPUS and Web of Science Databases in the period 2010-2018, using the following keywords: “cryptocurrency”, “Bitcoin” and “Ethereum”. The number of items was 771 for SCOPUS and 684 for the WoS database. Also, in this case, Economics (156 items) and Business Finance (125 items) were the main fields of discussion in WoS. In SCOPUS, Computer Science (269 items) did not overcome the cumulative sum of Economics, Econometrics, and Finance (217 items) and Business, Management, and Accounting (133 items). Country distribution confirmed the results by Alsmadi et al. (2022), with USA and UK leading the ranking, followed by China and Germany. The main keywords on SCOPUS and WoS were “Bitcoin” and “blockchain”.

The last article in our list is the systematic review of blockchain adoption issues conducted by Alshamsi et al. [46]. Before describing their research methodology, they provided an overview of relevant systematic reviews on fields of application, including those that focused on a single or few areas. The inclusion criteria for their study were:

- Time frame: 2010-2021.
- Involve a theoretical model for evaluating blockchain.
- Assess if blockchain has been adopted, accepted, or used with constancy.

- Only articles in English.

Accordingly, they defined their search protocol using the following search string: ((“Blockchain”) AND (“adoption” OR “acceptance” OR “use” OR “intention to use” OR “continued use” OR “continuous intention”)). The selected databases were Emerald, IEEE, ScienceDirect, Springer, MDPI, and Google Scholar. The articles included amount to 537. After a qualitative assessment, they selected thirty papers. The main domains were supply chain (12), education (3), and agriculture (3), followed by finance (2), logistics (2), manufacturing (1), the intelligence community (1), energy (1), tourism and hospitality (1), gaming (1), warehouse (1), and maritime shipping (1). They also studied prevailing models and theories used in blockchain adoption. The Technology Acceptance Model (TAM) was used in fourteen cases. Other options were Technology-Organization-Environment (TOE, eight appearances), Unified Theory of Acceptance and Use of Technology (UTAUT, 7), and Innovation Diffusion Theory (IDT, 5). Six different approaches appeared only once. Regarding external factors that limit blockchain adoption, the study showed that low adoption rates stem from inadequate knowledge of innovations. Trust (17 appearances), perceived costs (11), and social influence (11) affect the most, followed by facilitating conditions (10), performance expectancy (7), effort expectancy (7), and information security (7). Other concerns are privacy (5), complexity (5), compatibility (5), and top management (5).

1.5 Implications and Conclusions

Blockchain is a well-known technology that has been widely studied and implemented from a technical perspective, as well as its costs and limitations. However, when it comes to measuring its quantitative impact, the evidence is scarce.

Based on the methodology used by Sultan et al. [21] and Tasca and Tessone [30] at this stage, we conducted our research by exploring some specific issues:

- The definition and functioning of blockchain technology.
- The main research methodologies applied to blockchain research.

These topics are not comprehensive or definitive, but they are an essential starting point for understanding the current state of the art of research and the challenges, opportunities, and gaps that need to be addressed in the future, including potential fields of application and the significant implications from the policymaker’s perspective.

The literature has been mainly focused on system efficiency, legal, trust, cybersecurity, and governance implications. However, it also offers a considerable contribution to the debate in various relevant disciplines by introducing new themes, opportunities, and fields of application and evaluating its potential impact on different sectors. The technology framework still needs to be revised and more time to reach a complete level of development, and further updates are needed to enhance its efficiency and effectiveness.

We can summarize our results as follows:

- The oldest articles are no longer relevant to the current research. Technology has evolved rapidly, and the observations and findings are outdated. However, they provided valuable insights for the subsequent research activity. This result also implies that actors who want to adopt blockchain as an innovation for their actions and operations should be aware of the state of development of the technology and update their analyses of costs and benefits accordingly.
- Bibliometric and Scientometric approaches offer a helpful way to capture a large number of citations and identify research trends and gaps. Schneider and Borlund [47] argued that bibliometric methods could be used to understand and evaluate the work and the contents that must be investigated. Bibliometric studies can also analyze the patterns of international collaboration and the impact of multilateral scientific networks and joint publications as indicators of global research outcomes. According to Narin et al. [48], the basic principle of bibliometric analysis is to quantify scientific publications by measuring productivity through technical performance parameters. In recent years, bibliometric research has become an objective method for assessing the contribution of individuals to the advancement of knowledge.
- Through the quantitative analysis of blockchain literature provided by Lyu et al. [9] with their bibliometric approach, some suggestions for better development of blockchain are proposed: expanding the application of blockchain technology in various disciplines, strengthening the exchange of inter-blockchain technology, strengthening the research institutions of multiple institutions. In cooperation, they should actively seek scientific research institutions with complementary technologies. They can fully use the

advantages of universities and actively establish a technology R&D cooperation mechanism combining production, study, and research.

- A different contribution has been given by Tasca and Tessone [30] that provided a taxonomy on blockchain: although Blockchain is no longer an unexplored technology, taxonomies, recommendations, and overviews are still able to encourage research by helping people to have a first sight at this topic. Considering the continuous introduction of innovations, new challenges, trends, and perspectives, these articles are still needed.

The literature on these topics is abundant, but it is challenging to understand which direction researchers are taking. The research needs to be more consistent, clear, and mainly focused on the technology and its applications.

These results suggest that systematic literature reviews and mapping studies are the most effective and widely used approaches to address all the issues this new field of research could raise. Systematic mapping studies could be more appropriate for this research. These two methodologies could also be applied to specific areas of research. For example, several papers used this approach in particular contexts.

We noticed a gap in the core analysis of the actual impact in the real world, especially about the economic consequences of blockchain technology implementation. However, this is only true for some aspects: for example, many studies have already been conducted on the legal implications that a decentralized autonomous architecture could have on governance, responsibility, contracts, and law in general. A lively research activity can also be found on this innovation's ethical and philosophical implications. Two main reasons can explain this aspect:

(1) There are very few real-world applications in fields other than cryptocurrencies (therefore, we do not have benchmarks or data).

(2) The technological nature and the need for a comprehensive approach make it hard to develop models and frameworks helpful for researchers, businesses, and institutions.

Blockchain has many potential applications in various domains, such as finance, healthcare, supply chain, IoT, media, and government. Some examples of blockchain applications are:

- Money transfer. Blockchain enables secure, transparent, and private cross-border payments without intermediaries.

- Smart contracts. Blockchain enables self-executing contracts that enforce predefined rules and conditions without human intervention.
- Internet of Things (IoT). Blockchain enables secure and decentralized communication and coordination among IoT devices.
- Personal identity security. Blockchain enables verifiable and immutable digital identities that protect users' privacy and data.
- Healthcare. Blockchain enables the secure and transparent sharing of medical records among patients, providers, and insurers.
- Logistics. Blockchain enables traceable and efficient management of supply chains from origin to destination.
- Non-fungible tokens (NFTs). Blockchain enables unique and scarce digital assets representing art, music, collectibles, or anything else.
- Government. Blockchain enables transparent and accountable governance processes such as voting, taxation, or public services.
- Media. Blockchain enables decentralized and censorship-resistant content creation, distribution, and monetization platforms.

Blockchain can provide many benefits for public institutions, such as improving efficiency, reducing costs, enhancing trust, and fostering innovation. However, blockchain poses challenges and limitations, such as scalability, interoperability, regulation, education, and adoption. Therefore, policymakers need to carefully assess the opportunities and risks of blockchain technology for their specific contexts and objectives. They must also collaborate with other stakeholders, such as researchers, developers, businesses, and civil society, to create an enabling environment for blockchain innovation. Some implications and recommendations for policymakers are:

- Promote awareness and education on blockchain technology among public officials, citizens, and businesses.
- Support research and development on blockchain technology by funding projects, facilitating partnerships, and providing infrastructure.
- Establish transparent and flexible regulatory frameworks for blockchain technology that balances innovation with consumer protection, privacy, security, and social welfare.
- Adopt blockchain technology for public services where appropriate by identifying use cases, evaluating costs and benefits, and implementing pilots.

- Foster collaboration and coordination among distinct levels of government as well as with other countries and regions on blockchain policy issues.

In the next section, the study will examine the policymaker's perspective in more depth to provide an overview of the benefits and challenges of blockchain technology. It will also offer valuable recommendations for addressing the debate on introducing blockchain in the public sector and fostering innovation and stakeholder collaboration. A survey of application fields and two case studies for the public sector will complement the picture. These case studies could demonstrate how blockchain can enhance efficiency, transparency, security, and trust in public services and administration.

CHAPTER 2: THE ROLE OF THE POLICYMAKER: CHALLENGES, LIMITATIONS, AND FIELDS OF APPLICATION

2.1 Introduction

Blockchain technology is a new way of organizing and exchanging information in political, economic, and social domains by transforming modalities of engagement through which people, corporations, and institutions interact. This technology can empower individuals and communities, enhance efficiency and security, and foster social and economic inclusion [15, 8].

However, it raises crucial questions about the future of governance and democracy. It can create legal and regulatory uncertainties, ethical and social dilemmas, and technical and environmental problems. For example, blockchain technology can enable illicit activities, such as money laundering, tax evasion, and cybercrime, and can also raise issues of privacy, data protection, and digital identity [38, 15, 30]. Moreover, blockchain technology can negatively impact energy consumption, network scalability, and system interoperability [8].

Even more crucial, this phenomenon challenges the traditional role of centralized authorities, accelerating and consolidating the disintermediation process that social systems are experiencing in the twenty-first century [16]. Indeed, it enables people to interact directly without intermediaries [23].

Traditionally, we have relied on trusted intermediaries, which coordinate interactions between parties engaging in transactions, or centralized organizations that handle and bring together the most complex and intricate issues of society, define the regulatory and economic framework in which firms operate, and affect relevant aspects of the private life of citizens. As long as this authority fulfills its role effectively and performs efficiently, the user-citizen is willing to sacrifice some of their autonomy and unregulated freedom. However, as digitalization gradually reduces the importance of the human factor in our society, the relevance of centralized authority declines drastically.

Blockchain technology perfectly aligns with this dynamic: a technology that decentralizes control and limits ways of intervention and interference by a superordinate authority meets the cultural needs of modern society and adequately responds to the demand for freedom. Unlike governments, which impose their action coercively, blockchain architecture ensures legitimacy and authenticity by enforcing its own rule by code – as some authors argued [49] – without being perceived as an individual or a group of power. People, as individuals, forfeit the ability to influence the system. Still, it would be more accurate to say that the interaction among individuals and their direct participation in the blockchain architecture shapes and determines the system's functioning and framework, thereby eliminating or reducing the presence of a scarcely representative intermediary.

The main challenge that governments and public institutions face is defining the role the policymaker aspires to play in this emerging field. How will policymakers adapt to this changing environment? What are the opportunities and risks of this technology for society? How can policymakers evaluate their country's ability to innovate and adopt Blockchain? How can policymakers plan development strategies for Blockchain adoption using the policy tools?

The policymaker has a crucial role in addressing blockchain development and diffusion. The policymaker needs to balance the benefits and costs of this technology while ensuring that it serves the public interest and respects the values and rights of citizens while preventing abuse. Also, public institutions need to discuss how to implement blockchain within public services to benefit from these innovations' main advantages.

This section aims to provide an overview of the implications of blockchain technology for governments and society and some of the potential fields of application with a focus on public services.

2.2 Benefits, Challenges, and Opportunities for the Policymaker

Blockchain is a transformation driver that can lead from a traditional infrastructure where the government owns and is responsible for data and maintaining systems to a transformed information infrastructure and governance where multiple parties govern and transact [50].

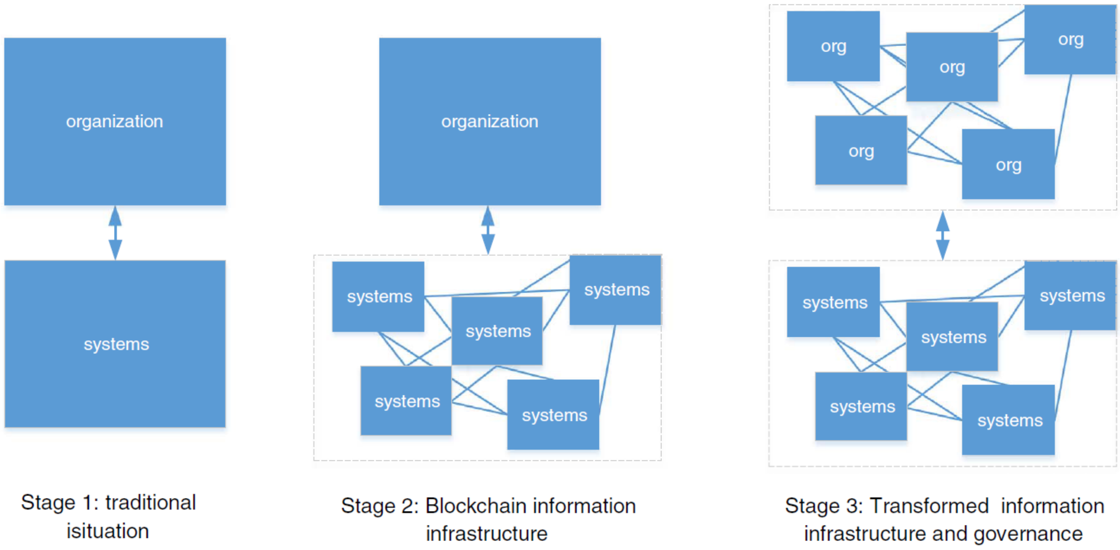

Figure 14 - Transformation from organization to network governance stages (source: Ølnes, et al., 2017)

Some of the potential benefits are the following[7]:

- Strategic benefits: transparency, fraud and manipulation prevention, corruption reduction. Distributed ledger storage enables democratic data access and prevents unauthorized alterations, thus avoiding fraud and corruption by ensuring ownership verifiability.
- Organizational benefits: enhanced trust, transparency, auditability, predictive capability, control, and ownership clarity. Immutable recordkeeping boosts trust and confidence. It also enables the creation of transaction history and audit trails. Blockchain might also promote inclusiveness.
- Economic benefits: cost reduction and resilience to spam and DDOS attacks. Economic benefits include lower investments in hacking protection systems.
- Informational benefits: data integrity and quality improvement, human error reduction, information access, privacy, and reliability. Automation and multiple nodes facilitate data access while preserving anonymity. Immutability also increases transparency.
- Technological benefits: resilience, security, persistency, irreversibility (immutability), and energy consumption reduction. Once data is recorded, it cannot be changed or deleted without system-wide authorization.

[7] The same feature can simultaneously belong to various categories of benefits or challenges.

However, limitations and challenges might include many of the features described above as potential benefits. Batubara et al. [51] conducted a systematic literature review to identify potential challenges and limitations from the policymaker's perspective and distinguish between three distinct groups - technological, organizational, and environmental contexts – according to the methodology by Tornatzky and Fleischer [52].

Technological challenges include design variables, immaturity, storage size, application platform, computation efficiency, flexibility, reliability, interoperability/compatibility, usability, scalability, and security.

Organizational challenges include auditing, trust, implications, new governance model, risk of error for business rules, business model/organizational transformation, cost-effectiveness, and organizational readiness.

Environmental challenges include support infrastructure, accessibility, acceptability, laws, and regulations support.

Technological issues dominate the discussion on potential challenges. Still, we can also find organizational and environmental problems referring to the ability of industries, populations, and society to adapt to this new infrastructure without entailing excessive stress on them. More in detail:

- Security and reliability. The security issues show ambivalence. On the one hand, the security of blockchain architecture makes it possible to reduce the potential loss or theft of information by unauthorized third parties. On the other hand, building a solid architecture comes with high implementation costs (developing and running the infrastructure). Outsourcing would, in some cases, require a prominent level of trust with the other party, given that only the system manager – once the system has been implemented – will be able to access information without constraints – even if data should be immutable and anonymous, according with what we said previously on blockchain features.
- Scalability, usability, interoperability. Undeniably, few countries can provide sufficiently advanced and widespread technologies and common standards to improve interoperability to adopt blockchain on a large scale. Implementation times and costs would increase significantly. Moreover, the lack of digital infrastructures would make vain any attempt to adopt blockchain, perhaps alongside traditional analogic systems, as the most outstanding advantages can be recorded in economies of scale.

- Existence of support infrastructure and accessibility. Other aspects may be considered: for example, the existence of support infrastructures and, therefore, a superior level of accessibility to guarantee that all users can use and take advantage of it. Many users would be left out without adequate infrastructure, causing unjustified inequalities.
- Computational efficiency and storage size. The technical aspect of computational efficiency and storage size are strictly connected with the previous one: blockchain technology is still at an early stage of development. As Batubara et al. [51], *"immaturity of the technology itself is at the base of all existing technological challenges in adopting blockchain"*. We briefly described what this implies when discussing the different consensus mechanisms and proposed solutions to improve scalability.
- Cost-effectiveness. The massive amount of data that a pervasive blockchain infrastructure should elaborate on would require an exceptional amount of energy and high-tech technologies, including conductors and semiconductors. At the same time, the world deals with energy and commodities shortages.
- Organizational readiness, organizational/business model transformation, acceptance. New governance models should be readily accepted since these platforms' effectiveness requires multiple parties, institutions, and economic actors to cooperate by becoming part of the system and providing all the necessary data and information. Businesses and users should already be able to welcome the introduced innovations, not only from a technological point of view – that is quite a challenge -but also from a cultural and economic point of view. Alternatively, we should have a context favorable to rapid changes, an infrequent feature for cultural and organizational contexts where blockchain would have the most disruptive impact. We can also include some sub-challenges in this set, for example, auditing and risk for error for complex business rules.
- Trust. Building trust is the most formidable challenge for policymakers, especially concerning digitalization and recent technologies. Although trust, transparency, and anonymity should be considered the most prominent benefits of blockchain, its complexity and the absence of centralized control could lead to a complete lack of confidence. This would only slow down its implementation, primarily due to implications that governments and

businesses would be forced to face. For example, a lack of trust in a new reporting system can lead a company to a reduction in the number of customers. On the government side, the political impact of a disruptive reform will be measured in future elections. Suppose it is not carried out with due caution and care. In that case, introducing a blockchain infrastructure can break the spirit of stakeholder cooperation, contradicting what was said above.

- Laws and regulations. The role of the regulatory framework is essential because it clarifies what is allowed – and what is not – within the latest information management system that claims to go beyond traditional techniques. The level of acceptance strongly depends on rules and clarity. Policymakers can deal with the nature of blockchain technology, expanding the law to cover new activities that are related to blockchain technology.
- Immutability. Unlike traditional record systems, information is unlikely to be modified or edited once it enters the chain. Human errors might be hazardous.

The policymaker should also investigate smart contracts' role within traditional legal systems. Satoshi Nakamoto never used the concept of "smart contracts" (or "contracts"). Considering that each transaction is technically a contract, in the case of blockchain technology – but this is generally true for all instances in which similar protocol can be utilized – we need to introduce the concept of "smart contracts". A smart contract is a "computerized protocol that executes the terms of a contract" [53]. Thus, it is written using lines of code that can be automatically executed by a computing machine [24].

An immediate consequence of the self-executing and self-enforcing feature of smart contracts is the absence of the need for a third party, an intermediate, or a legal system that controls and verifies the execution and eventually provides actions that can enforce it. In a blockchain system, every smart contract would be recorded as a trackable and irreversible transaction in the distributed database, allowing the possibility to check it for each node of the network, and due to the self-executing/self-enforcing characteristic, there is no risk of not fulfilling it, thus enhancing transparency and trustiness. If smart contracts are applied to different areas, we will observe the need for policy maker to define an adequate regulatory framework. A further application area would be supply chains, where the clear benefit of using blockchain technology includes strengthening criteria for registering, certifying, and tracking goods at lower costs than traditional supply chain architectures. Smart contracts fit perfectly into this class of activities.

Current ways of influencing blockchain governance by policymakers might be inadequate because of the unique features of this “alegal” technological artifact. Accordingly, they should look for alternative ways of intervening in blockchain-based systems [54].

McQuinn and Castro provided suggestions for the policymaker to engage and actively support the adoption of blockchain technology positively. To this end, policymakers could adopt a tech-neutral approach. The authors suggest that policymakers consider each project and technology's benefits and challenges rather than favor one and recommend that policymakers apply existing rules to comparable products and services, regardless of the technology used. It implies that policymakers should create clear and consistent management and regulations for blockchain applications to avoid confusion and uncertainty for developers and users and promote legal certainty for blockchain applications, both at a national and supranational level – establishing international standards and promoting interoperability. Moreover, policymakers should adopt blockchain solutions for public services, reform their procurement process to include blockchain companies better, and support research and development. The regulatory framework should avoid laws that prevent the adoption of blockchain solutions. At the same time, it should incorporate flexibility to enable experimentation in this field. The government should incentivize companies and firms through targeted regulatory enforcement to protect consumers when introducing innovations [23].

Some authors discuss the issues of blockchain integration into public services from a conceptual point of view - by building systematic literature reviews on blockchain technology and its potential use as a validating protocol and authentication system for persistent documents in the public sector.

Svein Ølnes [55] conducted a systematic literature review on Bitcoin-related papers and selected use cases relevant to the public sector. In 2016 most of the scientific literature was focused on Bitcoin, while there was a lack of public sector studies both from a theoretical and an empirical point of view. His primary source was the e-Government Research Library (EGRL) v. 11.5, expressly indicated for electronic government and governance studies. He also included content from the Web of Science and Google Scholar. The search protocol included the keyword “blockchain” OR “bitcoin” for EGRL, “bitcoin e-Government”, or “blockchain e-Government” (OR “eGovernment”) in Google Scholar and Web of Science, but the search returned zero contents. Finally, he added the “Bitcoin Academic Research” compiled by Brent Scott [56], where 627 articles were cataloged into four different areas: economy (244), technology (241), legal or regulatory (107), and others (35)[8].

Ølnes labeled Bitcoin as an information infrastructure since it has the following properties:

- shared universally and across multiple IT capabilities.
- open (and unbounded) to new connections and new capabilities.
- technical and social heterogeneity.
- attitude to evolve over time.
- the organizing principle shows signs of recursion.
- distributed and dynamically managed control.

To study the potential disruptive impact of blockchain, Ølnes proposed a use case for Academic Certificates designed by Andreas Antonopoulos (blockchain technologist) to store the academic certificates of his MOOC-based course (Massive Open Online Course) “Introduction to Digital Currencies” held at the University of Nicosia. According to the characterization of Bitcoin technology and information infrastructure, the storing system should have the following features: (a) using only a Bitcoin blockchain, (b) allowing authenticating a certificate without having contact with the university, (c) allowing fulfilling the process even if the institution – and their website - does not longer exist. In conclusion, the author argued that blockchain technology could be usefully implemented for operation in public services with more efficiency and effectiveness than other technologies still used. Thus, blockchain can help innovate the development of digital services in the public sector.

Other implications come from the adoption of blockchain solutions for public services.

On the one hand, efficiency, and cost-effectiveness can be significantly improved by reducing reliance on bureaucracy. This applies, for example, to the storage of all legal documents, including IDs, passports, land registries, contracts, etc. [16]. This increase in efficiency would indeed impact citizens’ perception of public administration. Therefore,

[8] Brent Scott’s search databases were: JSTOR, ScienceDirect, SpringerLink, SSRN, Taylor & Francis, Google Scholar, and Wiley Online Library.

the problem mentioned above of lack of trust would not refer to the undoubtedly positive effect of the practical application of blockchain to public services.

On the other hand, the question is how willing people are to give up the human factor in the public sector. The transition to blockchain architecture is a step toward full transparency and efficiency in a society with high trust and observance of the law. The privacy should not even be an issue since blockchain grants anonymity. When the level of trust is low, people would perceive blockchain as an attempt to limit their freedom of action – interpreted as the possibility to circumvent rules and laws but also to restrict their privacy. There may be a repulsion towards an automated system based on blockchains replacing bureaucracy [57]. Not surprisingly, academic literature has studied the benefits that blockchain technology would give developing countries affected by high crime and corruption [58].

As argued by Kassen, M. [59], governments should adopt a cautious approach when managing data and public information, moving along the lines of development and technological progress. Even if the author highlighted the benefits and efficiency of blockchain for this field of application, he introduced new challenges and practical implications related to data management and storage:

- managing (essential and unimportant) information and history of information retention.
- the importance of creating a critical mass of peers in the network.
- information security, transparency, and confidentiality.
- non-repudiation in e-government data management (non-reversibility of data recording).

Data would no longer be deleted after they have been registered. Any change would be detected, and the information would be transmitted to the whole network. Blockchain urges us to rethink public services. Potential applications include tax collection, identity management, distribution of benefits, local (or national) digital currencies, property, land registries, etc. As discussed, it will be necessary to find a compromise between privacy and data protection.

More implications could come in the long term. For example, blockchain could support the diffusion of transnational services that overcome boundaries and state jurisdiction. Furthermore, blockchain can be used for the direct participation of citizens in the decision-making process, thus further reducing operating space for governments.

The central authority would still have a role, but mainly as a supervisor with a regulatory function [16].

In 2017, the European Parliamentary Research Service published a paper discussing blockchain technology's potential impact on our lives. The authors have cautiously identified this new framework's problems and challenges but adequately described potential benefits [60].

In particular, they recognize the ability of blockchain to improve public services thanks to renewed efficiency and cost-effectiveness. They also acknowledge that some of the most relevant features, such as transparency, can be good for some services (e.g., land registries) but would be risky for other areas, such as bank balances and other sensitive data because blockchain could compromise the privacy and anonymity of transactions. Although blockchain assures these aspects, we cannot ignore that some information needs to be accessible to operators precisely for the purposes they were delivered.

Undoubtedly, blockchain represents the most effective tool for managing rights associated with digital content. Introducing a transaction authentication system and smart contracts would facilitate all procedures for registering and protecting rights, thus eliminating unauthorized use of restricted content. Another practical application is the e-voting system, which aims at restoring links between citizens and political institutions.

A similar discussion can be made for patents. The policymaker could introduce a unified patent system that would significantly reduce transaction costs and the need for information exchange. This would have a relevant impact on the abuse of patents. Innovators could use this process and infrastructure to protect their work while keeping innovation details private. In this case, blockchain would function as a “proof-of-existence” service instead of a “patent protection” service.

Finally, blockchain can be used to develop decentralized structures inside organizations, eliminating errors and corruption introduced by humans. Decentralized Autonomous Organizations (DAOs) lie in an unregulated grey area. Governments will soon have to define the regulatory framework in which they operate.

Clavin et al. [61] studied which blockchain architecture would better fit the government’s needs. Most blockchain implementations in the public sector are permissioned, with few exceptions where permissionless blockchains work in a closed, privileged setting. The authors argue that blockchain can be used for various applications that require high reliability and data quality. However, it also creates new risks and challenges that need to be solved. Blockchains may shift the role of trusted brokers to data centers or cloud providers. Finally, blockchains have evolved from cryptocurrencies to more general purposes, especially in government domains.

Governments can use blockchain technology to build networked public services that share data across agencies and departments more efficiently and securely. Solutions that use blockchain to speed transactions by allowing digital verification and signing of documents will respect the privacy and ownership of individuals and organizations in a data-sharing environment where each person or organization would have their own ledger in a blockchain database that they can control and share with government agencies as needed [62].

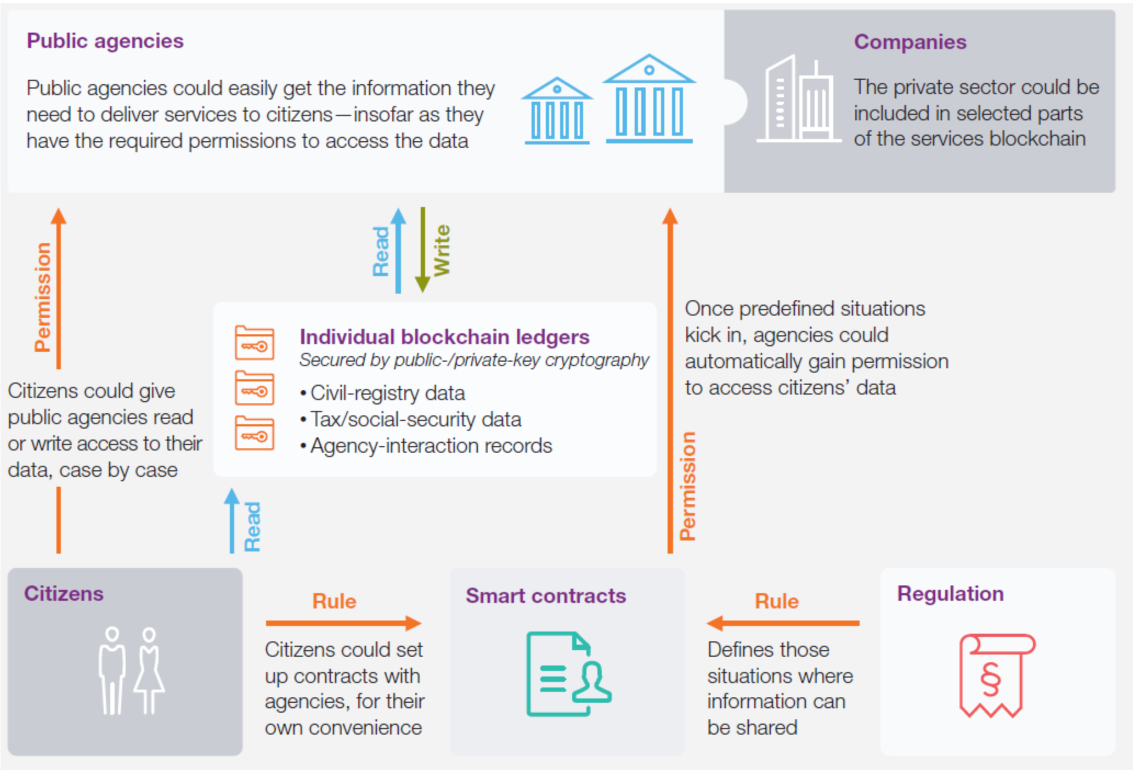

Figure 15 - Source: McKinsey analysis (Source: Cheng, Daub, Domeyer, & Lundqvist, 2017)

Although academia and industry cannot refrain from discussing potential impact and implications, the study so far highlights that the role of the policymaker is still decisive in facing the new challenges posed by this innovation.

Applications of blockchain technology go far beyond what could have been expected at the beginning of its development. In less than fifteen years after its advent in 2008, the blockchain entered mainstream research. It has come onto the policy agenda of many countries and institutions, including the private sector and state-owned companies, research organizations, small local entities, and municipalities. We can assert that the first stage of discussion, focused only on cryptocurrencies and digital currencies, has been largely passed. The scientific literature is now expanding to numerous other areas, thereby introducing efficient solutions and exploring new options that could benefit several fields, especially regarding the well-known efficiency and effectiveness issues from which many countries, institutions, and public administrations are affected.

2.3 Survey of Fields of Application

The first application of blockchain technology in cryptocurrencies had a remarkable impact on traditional financial services and payment methods. Still, the real potential of this innovation is much broader and more profound. A survey of the application fields is needed to understand the disruptive implications for finance, economics, governments, and society. Different survey on fields has been produced in the last few years to help categorize its potentiality.

However, it is challenging to find a fully comprehensive review describing in detail possible fields of application - already taken into consideration or still to be explored by the literature. To address this issue, we carried out a systematic literature review by assessing results from our previous systematic mapping study and adding more articles using reference works of relevant articles (snowball effect). The hand-search reference list added helpful papers, reports, and policy suggestions, mostly from official committees within public institutions and international organizations.

Indeed, the attention to this innovation also comes from governmental and international institutions. In 2017, the European Parliament Research Institute published a document titled “How blockchain technology could change our Lives” written by Boucher, P., Nascimento, S., and Kritikos, M., which is a survey of blockchain applications to some essential public services, and others relevant fields, considering that blockchain is ideally suited to create efficient, non-expensive and secure public records, without any adverse effect on privacy and anonymity, thus differentiating its utilization to the non-financial sector. Not surprisingly, recently, central banks and other public authorities have urgently embarked on a debate about the creation and possible usage of new so-called “stablecoins” as new digital currencies to be combined with traditional currencies in the context of payment systems and frameworks.

Here is a survey of potential application fields for blockchain technology (BCT):

- Financial sector. Blockchain can address trust issues, high transaction costs, and the probability of fraud through a redefinition of payments systems and the digitalization and inclusion in a blockchain of financial assets (smart contracts) with several impacts on risk management [63, 64, 60, 65, 66, 67, 15, 68]. Chain.com provide a platform for private equity exchange on top of Blockchain [67]. Other applications include securities and insurance products [60], clearing and settlements of financial assets, client account reconciliations, peer-to-peer financial markets, and enterprise transformation for traditional postal operators [69, 70]. BCT also offers solutions for governments and central banks for activities like cash management and treasury activity (Treasure Single Account) [71], banking operations, Over-The-Counter contracts/products, clearing and settlement, automated client account reconciliations, and loss data [70]. BCT can impact financial inclusion processes and support systems of micro-finance, micro-loans, remittances, cooperative frameworks, etc. [56]

- Decentralized autonomous organizations (DAOs). One of the most innovative applications in society could be the creation of more independent, decentralized, and agile organizations that would use blockchain to facilitate resource management, for example, using platform cooperatives and smart contracts, totally changing social and economic dynamics [60].

- Internet of Things (IoT). one of the most promising information and communication technologies (ICT), has recently ramped up. IoT aims to integrate things (usually called smart objects) into the internet and support users with numerous services. BCT can potentially improve the IoT by proposing new e-business models based on smart properties and smart contracts, with the contribution offered by distributed autonomous corporations (DAC) as a decentralized transaction entity [15]. Some applications could be the Internet of Vehicles, the Internet of Energy, the Internet of Cloud, and Fog computing [72]. One example is Walton, a project primarily used for RFID and IoT but to scale to the business ecosystem, or VeChain, currently used for food and drug sectors [73].

- Supply chain and international trade. BCT could provide a valuable infrastructure to register, certify and track each good or service a firm offers, even between two actors who do not interact directly, thus enhancing transparency and accountability. This technology can be proposed as a solution for trust and logistic issues in the supply chain. Goods are linked to a unique token that is transferred via the blockchain. This application can be implemented using smart contracts [60, 74, 75, 67]. Blockchain technology enforces transparency for the producer and ensures visibility to the customer, who can get information and details about the product and its traceability. This can solve many logistical, cost, and transparency issues that affect the growth and operation of global value chains, especially in the case of energy, food, agribusiness, and pharmaceuticals, but in general international trade [74].

- Security. BCT can tremendously improve the security of distributed networks and the reliability of security infrastructure by avoiding centralized countermeasures vulnerable to malicious attackers or improving the reliability of conventional public vital infrastructures [15].

- Privacy and protection of personal data. Another critical issue is the increasing exposure of personal data to malware. BCT can provide a decentralized confidential data management system that protects data against issues like data ownership, transparency, auditability, and fine-grained access control by distributing data in a decentralized manner [15].

- Reputation. Current reputation systems on the Internet are affected by fraud and revenge ratings, and detecting dishonest reviewers is hard because they can act strategically to hide their identities. Blockchain systems effectively prevent bad-mouthing and whitewashing. Also, reputational issues emerge in other contexts, like members of web communities or academics. An organization can create blockchain awards for staff members, and all the reputation changes can be detected easily through changes in the number of digital coins or blocks. Another contribution could come from adopting architectures able to prove manufacturing provenance without the authentication of parties registered anonymously [15].

- Digital content and rights management. BCT could manage consumer and creator rights associated with digital products and unique digital artworks by recording the ownership history of digital property and enforcing digital rights. It can also be used to record sales, loans, donations, and transactions/transfers of each digital artifact, with the agreement of all the blockchain users, without any deterioration of the information on the creator or other previous owners. In this case, smart contracts are necessary to enforce this transaction mechanism [60, 15].

- Patents. A similar application can be used for patents and innovation, protecting inventors while reducing contract disputes and claims and correcting distortions in a fragmented market, even in a contest like the European Union, where a unified patent system has not yet been implemented [60].

- E-voting. BCT can also be used to implement an open voting record amongst the citizens, facilitating the process without security issues (at a centralized level) and facilitating engagement with people in making crucial decisions. Its potential is so evident that Blockchain-enabled e-voting has already been implemented in Denmark for discussions within political parties and in Estonia for shareholders' ballots. If combined with smart contracts, its impact could be even more disruptive; for example, election results realized via BCT could automatically trigger the approval of a law/manifesto promise or other decision of the winning party, which would be forced to align its ambition to an actual capability to implement it [60]. In 2015, the Bitcoin Foundation started a project to develop a blockchain-based voting system [15].

- Free speech right. BCT is ideal for securing internet features like DNS and hardware digital identities. For example, Namecoin aims to make the web resistant to censorship by improving decentralization, security, censorship resistance, privacy, and speed of DNS and identities, protecting free speech rights online thanks to the distributed ledger mechanism [15].

- Public registers. Blockchain can be used to conduct transactions and create records (e-identities, birth certificates, business licenses, public notaries, patient records, land registers, marriage registration, income taxation systems, etc.) accessible to all administrations and citizens who need [60, 62, 15]. Key public sector activities that can be recorded, stored, and managed include public activity log data (who, when, and why someone accesses data or replaces it), public cross-agency data to improve administrative cooperation, public urban data (linked to smart cities, transport, food tracking, etc.), data on government procurement with the help of smart contracts [59]. uPort is a government-issued identity on the Ethereum blockchain that the City of Zug has recently introduced. The project aims to offer a reliable and self-sufficient blockchain-based identity that can verify for e-government services and share personal information with third parties. [76]. Dubai has developed a blockchain-based public service to list business activities [77].

- Land registries. Some countries have already begun using blockchains to manage land registries, land information, and related rights (Ghana, Kenya, Nigeria) to guarantee a correct classification and a transparent and trustworthy record of ownership or any change made to it. For example, Sweden is conducting tests to apply the BCT to real estate transactions, like the project developed by Lantmäteriet (the Swedish mapping, cadaster, and land registration authority), Telia, ChromaWay, and Kairos Future [78]. The National Agency of Public Registry (NAPR) of the Republic of Georgia uses blockchain technology to provide its citizens with a digital certificate of their land title [76, 79]. Other hybrid approaches have been studied to evaluate a more scaled operational and production-level implementation of BCT in this sector [80].

- Public and social welfare services. The UK is evaluating introducing a blockchain mechanism for welfare payments ([60]. In the Netherlands, the

Dutch pension provider APG is exploring multiple use cases for blockchain technology, like Pension Infrastructure, a complete community-based pension administration blockchain back-office. [76]. Also, voucher systems could be updated by using blockchain. Vouchers are one instrument of providing social welfare to citizens, but they have several security problems, such as counterfeiting, duplication, and low operational efficiency. Some researchers investigated using BCT and cryptography to create an efficient and trustable e-voucher architecture that can overcome the drawbacks of vouchers. Hsu, Tu, and Huang [81] demonstrated that this model satisfies the security requirements in the case of the Hyperledger Fabric blockchain platform for Kafka ordering services for issuing meal vouchers in campuses. Another practical example is given by Stadjerspas, a fully operable service that uses blockchain infrastructure to provide discounted services to low-income citizens of the Municipality of Groningen (Netherlands) [81, 76]. In addition, some authors showed through empirical research that BCT could significantly enhance users' trust in charitable projects, increase the honesty rate and improve the quality of donated materials. Moreover, it can boost the social welfare output produced by charity donations. The blockchain platform is a technical solution that maximizes social welfare [82]. Different studies investigate the acceptance of BCT as a solution to the problem of welfare services for people with disabilities, and the findings are controversial [83].

- Transport sector. Connecting mobility services and autonomous vehicles [84]. Another application has been proposed by T-Mining, a Belgian organization operating in partnership with NxtPort for container shipping [73].

- Energy sector. BCT can be used to encourage the usage of green energy and renewable electricity generation in countries' grids [85, 84, 15, 61]. In a technical report published by the Joint Research Center, we can find a proposal for a distributed ledger that could help citizens to participate in a genuinely free, open, and interoperable energy market, where consumers can produce green energy within their houses and distribute it to the local community, with high levels of transparency, trust, accountability, security, while preserving privacy requirements, and possibly opening up a new set of business opportunities [74]. Such an infrastructure could work independently from a central grid but could also be connected to it [85]. Using smart contracts and off-chain interaction technologies, this mechanism could be applied to all kinds of energy and heat markets, totally changing the transaction framework of energy trading currently used and introducing a Distributed-Integrated Energy Trading Transaction Framework among virtual power plants while improving energy efficiency in supply chains and transportation solutions [67, 86].

- Healthcare and Pharma sectors. BCT can be used to trace the origins of goods reliably [84] and is relatively spread in the development of Electronic Health Records [61]. Blockchain could help contemporary clinical research overcome medical challenges by ensuring data integrity, traceability, automation, and fine-grained control for clinical trials [87]. More in detail, a functional BCT applied to healthcare needs to have the following essential requirements: product identification, product tracing, product verification, detection, and response system in case of counterfeit or dangerous products, a notification system when an illegitimate drug is found, information requirement [73]. There are several existing applications of BCT to healthcare: MedRec [88], Wellderly [89], Enigma [61], and Patientory [90] propose the use of a patent-managed health information exchange applications; FarmTrust is a UK organization developing blockchain solution for pharmaceutical supply chain [73]; Nebula Genomics and Luna DNA suggest to share and analyze genomic data on BC platform; ModelChain is a Hyperledger platform adopted to enhance research and enable quality improvement initiatives by supporting decentralized cross-institutional predictive modeling for oncology clinical data [90]; blockchain can also be adopted in clinical data sharing and automated remote patient monitoring [89, 90].

- Education. The Joint Research Center provided a report on the application of BCT in Education. The report concludes that it can be easily applied to accelerate the end of paper-based systems for certificates, to allow users to be able to automatically verify the validity of certificates, to intellectual property management, for the tracking of publications and citations, to create data management structures to reduce educational organizations' data management costs, to facilitate payments within some institutions [91]. For example, in October 2017, Malta started a project about academic credentials based on Blockcerts to enhance transparency and trust in verification procedures. The aim is to create a verifiable proof of education for people [76]. BCT can also be easily applied to the online educational market, creating learning blocks that teachers can pack and place in blockchain, and learning achievements can be considered coins [15]. A practical application is The LinkLab, a blockchain organization partnered with Chronicled for the implementation of distributed knowledge and development resources [73].

- Agriculture and food industry. The agriculture and food supply chains are among the most complex and challenging. There are limits to developing global and efficient solutions for transparency and traceability. The BCT could enable traceability in the agri-food domain by introducing a mechanism to store essential data, thus helping the recognizability of products, therefore protecting local or typical brands [92, 93]. This possibility has already been implemented in many projects and initiatives, but it needs cooperation by governments, institutions, and all the stakeholders operating along the supply chain. BTC could improve the food system's sustainability, ensuring security, reliability, transparency, and food safety and integrity, while enhancing efficiency and cost reduction [94, 93]. IBM Blockchain is a tentative supply chain management in food products with multiple partners. Provenance is a UK organization starting with chain-of-custody of food [73].

- Smart cities and tourism. The development of smart cities benefits from ICT. Also, the tourism and hospitality industry has applied blockchain since 2014 [95]. Smart cities are collaborative environments where people and infrastructures are organized in a system with increased levels of efficiency to improve the quality of life, all desirable features to develop tourism in an area. If considered along with blockchain-related technologies, introducing smart contracts and other essential characteristics to the ordinary life of a city could work on various levels. The architecture would work on six layers (infrastructure, data, platform, policy, citizen, and traveler) and is strictly connected to the diffusion of cryptocurrencies, innovative payment methods, blockchain-based public services, instruments to manage and record personal data (like clinical ones), more efficient supply chains, distributed autonomous apps (DApps, such as Globaltourist, Locktrip, Travala, Travelflex, and others) and other token-based methods of interaction [96, 97]

- Luxury. Other fields of application can be considered. For example, the luxury products market could use BCT as a solution against false and counterfeit products, and Block Verify is an existing technology already used for this purpose [73].

The following section will discuss the tangible advantages blockchain applications to public services could provide citizens and businesses. To this extent, we will start by looking in more detail at case studies of blockchain applications to public services in the EU among those mentioned above. Case studies would help us to understand how this innovation can have enough acceptance from policy maker and citizens to foster a widespread diffusion at various levels. Some countries started to look at potential benefits, especially in terms of transparency, lack of trust, and reduction of illegal behavior.

2.4 Case Studies as a Framework to Support Blockchain Adoption in Public Services

Whether theoretical or practical, the analysis of case studies enhances blockchain research, offering innovative solutions and unexplored perspectives for current knowledge. Still, most importantly, it allows for identifying operational frameworks that can be easily scaled in various dimensions and contexts. Moreover, considering the cumbersome nature of the public sector, especially in advanced countries, and its difficulty in renewing its infrastructures - not only technologically but also legally and, even more importantly, culturally - the creation of case studies is an indispensable support tool for the development of solutions consistent with the current technological and cultural framework.

Yin [98] defines a case study as *"an empirical inquiry that investigates a contemporary phenomenon (the 'case') in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident"*. Case studies are specifically helpful when research wants a clearer picture of a situation where we can observe many more variables of interest than data points, thereby making converging methodologies and data structure necessary to facilitate future analyses.

Horst Treiblmaier [22] contributed significantly by proposing a rigorous methodological approach for writing Blockchain case studies. An overall description of his research has already been provided in Section 1.4. He has benefited from previous research to identify some practical issues that could arise when moving to the implementation stage of blockchain technology. The main challenges can be collected into a few groups:

- Throughput. The performance offered by currently existing public blockchain platforms seems inadequate to support the amount of data that today's data collection systems are needed to collect and process, mainly due to the need to adhere to solid consensus mechanisms [99, 100].
- Size and bandwidth. Blockchains grow over time, absorbing capacity and bandwidth [100].
- Latency. It is well-known that latency in data processing increases as the number of nodes increases[9] [100].
- Resources usage. Redundancy in data transmission, storage issues, and energy consumption [8].
- Regulation. Legislation has a preeminent role in addressing this problem, but parliaments lag behind technological developments, thus creating uncertainty for organizations and slowing down their tendency to innovate [76].

[9] This problem is already known in the infrastructure used by Bitcoin. Undoubtedly more efficient results can be obtained in the case of permissioned blockchain, that is a model - among other things - more appropriate for the characteristics and needs of public services, where we can observe the attitude to centralize the data collection, management, and processing of information - especially personal information -, approach founded on obvious political reasons. However, it cannot be excluded that the public authority decides to outsource some steps of the process, as is the case, for example, in Italy for SPID, where private companies are remunerated to offer users a digital identity service that allows them to access information managed by government agencies.

- Usability, versioning, multiple chains, and specification of standards. The absence of standards at various levels makes shared blockchain frameworks more complex [76, 51]. It includes issues related to access rights, data structures, and allowable transactions [101].
- Privacy: Issues related to privacy come from the immutability of data, especially for that information attaining an identifiable person. On the one hand, laws and rules are still in their infancy, but on the other hand, blockchain has the potential to strengthen cybersecurity and privacy [102].
- Trustworthiness of records. If the blockchain allows individuals to control and operate their data, it cannot be adopted as a solution for keeping trustworthy digital records [103].
- Viable ecosystem. Companies would generally benefit when many users access blockchain solutions to obtain a significant impact from their implementation[10] [22].
- Shared governance. Decentralized governance would be viewed negatively by the government [50].
- Attack Surface. Blockchain is commonly misinterpreted as a secure-by-design technology, but these features cannot withstand all cybersecurity threats [104].

Some of the most promising case studies in Europe have been reported by Allessie et al. [76]. In the JRC report, they examined different experiences in some member states and provided a list of seven projects in the public sector. They developed a customized case study assessment framework where they distinguish among institutional, functional, technical, and economic aspects of each case study. They conducted desk research on each project and structured a format for interviews with representatives from each developing team. In particular, they grouped the aspects mentioned above into four layers:

- Project characteristics. This describes in which country the project is being launched, the level of government involved if the pilot applies to multiple

[10] It should be taken for granted that services offered by the government would benefit the most from exploiting such tools. Given the vast number of people who would have access to public services, the absence of such legislation is only preventing or postponing a process that could have far from negative implications in terms of efficiency and transparency.

sectors or countries, and other information about the openness of the software, the location, or the local community.

- Functionalities, governance, and usage. It identifies the functionalities of the specific software and the blockchain-based service, including the governance structure, the blockchain protocol, the current use of the service, the functions executed by the platform, and the extent to which the service can disintermediate existing services and institutions.
- Technical architecture. This layer describes the technical specificities of the infrastructure. It collects information about the distributed ledger technologies involved and other non-distributed ledger technologies that may be used in the pilot.
- Costs and benefits. Finally, the authors described the potential benefits and costs involved in the development and operation of each service to understand if it would be sustainable in financial terms.

The JRC report analyzes, among others, the Dutch experience of two ambitious initiatives in the concrete application of the blockchain to the national pension infrastructure starting from a local-level pilot project for assistance to residents: the Pension Infrastructure project and The Stadjerspas project – the first at an early stage of implementation and the second already fully operational. Both of them bring evident benefits in terms of efficiency and cost-savings.

The PI – Pension Infrastructure project launched by Algemene Pensioen Groep (APG)[11] and PGGM Coöperatie U.A (Stichting Pensioenfonds Zorg en Welzijn, known as PFZW, formerly PGGM, Pension Fund for Care and Well-Being)[12], the two largest Dutch pension manager companies, envisions a fully blockchain-based pension back-office system aimed at achieving a flexible working environment that is transparent to retirees and has significantly lower operating costs. The principle on which the initiative is based is, after all, straightforward. Indeed, the evolution of the global economy, which aims at flexible and fixed-term work, leads toward future scenarios of individuals of

[11] APG is a pension provider that manages a total capital of over five hundred billion euros in pension funds for employees in the government and education sector, offering income security to more than three million members and beneficiaries.

[12] PFZW is the second largest pension fund in the Netherlands, with total assets under management of about 227 billion euros for 4.3 million participants.

retirement age at the outcome of a varied working life characterized by several experiences with multiple employers or by professional services provided for limited times to various individuals, thus generating a multitude of pension data from different sources and often from different countries. Therefore, it falls to the national pension system to correlate this data and reconstruct the individual worker's pension history. This challenging task involves high management costs and numerous hours-work, making the system less efficient. The PI project appears to be able to overcome these issues through a computerized system of data storage and management system that is tamper-proof and unintended loss-proof.

We can identify the project's key features by applying the assessment framework proposed by Allessie et al. [76].

Regarding project characteristics, the involved level of government is national since it provides a national public service, pension administration. It does not present cross-national aspects at this level – but we can imagine a European pension system in perspective – but includes cross-sector elements.

The governance set-up lies on a hybrid-federated system where we can find centralized control of technical aspects by APG e PGGM, integration with various existing pension systems, and decentralized governance facilities co-creation of distributed database. The provider should maintain some control over the system to adapt smart contracts to changes in the real world and regulatory environment. The system would not disintermediate the national pension institution but could automate transactions and data collection. In terms of governance, it needs the involvement of the government, businesses, users, and the tech provider.

The software is open source, but the code can be modified only with authorization. The infrastructure is based on a private permissioned blockchain architecture that uses a tweaked version of the Ethereum protocol, a Proof-of-stake blockchain consensus mechanism. The blockchain collects data, but we do not have information on storing transaction details. It also uses non-DLT systems like the salary database and the pension database.

From a technical point of view, we know that PI will use identity-based authentication from the national citizens and identities registry (BRP). We can suppose that the pension infrastructure ledger contains an overview of the transactions that occur in the entire lifecycle of a worker, including, for example, transfers of funds between different pension funds, as well as salary variations. The system would rely on providing external data from various sources and databases – pension fund databases, employment systems, and tax authorities. To some extent, the database could be shared among partners and sources so that each stakeholder can receive outputs from the infrastructure. It is at a proof-of-concept phase, so we do not have usable data on usage, capacity, throughput, scalability, and maturity. The first completed test was based on the pension data of APG's employees, with about five thousand participants.

In terms of costs, no data are available. However, in terms of savings, some analysis from the provider shows that the project can result in savings of about five hundred million euros against the current total cost of one billion euros for the pension administration in the Netherlands. Creating a distributed database among several sources, systems, and institutions would improve efficiency. Savings would come from lower administration costs and lower transaction costs. It also brings qualitative benefits like increased transparency, security of data, and enhanced regulatory oversight. We do not have information on development and implementation costs.

According to both PGGM and APG, the proof-of-concept phase was successful, and the results are encouraging.

On the other hand, on the front of public welfare instruments toward the economically disadvantaged population, the JRC report analyzes the experience made by the municipality of Groningen. With the Stadjerspas project, the local government has introduced a social inclusion system that uses blockchain to ensure disadvantaged people can enjoy certain services at reduced prices, replacing the previous set-up entirely based on paper vouchers. According to the JRC report, up until 2013, vouchers were paper-based. In 2016 the voucher system was updated to its blockchain version.

With this innovation, the municipality has achieved high levels of transparency and stability of the system but, above all, a marked improvement in the management of the allocation phase of public resources for the objectives set, tying the disbursement of benefits to compliance with specific conditions - income or personal of the beneficiary, spending on particular services, spending in general- contained in the smart voucher underlying the granting of the social benefit and expendable via a QR code sent to the citizen's smartphone. The governance is based on a multi-stakeholder system where the municipality of Groningen, the technology provider (DutchChain Systems), citizens from Groningen and Ten Boer, and businesses participate in the blockchain.

The transactions are stored and performed on a semi-public blockchain architecture called Zcash – after an initial usage of the Bitcoin protocol. Transactions are public, but users are permissioned. However, the blockchain does not store transaction details. Each user can apply through a unique ID. The system checks if the user is eligible for any smart vouchers, each one linked to a particular service. The infrastructure uses smart voucher functionality and automatic payments through the SEPA system. Payments occur after some time, thus strengthening the transparency and programmability of public resources. The Stadjerspas project is fully operational in Groningen and, to date, has more than 20,000 registered positions - among citizens, users, and service providers - and a volume of smart vouchers disbursed of about 4,000 per month.

In terms of costs and benefits, gains in efficiency for the municipality and transparency for all stakeholders are evident. We do not have information on project costs, but the project has been selected through a competitive public tender. Moreover, the Zcash system is cheaper than the Bitcoin protocol, thus improving savings after the migration. Citizens' access is free of charge.

Despite the potential success of the described cases, governments' and public authorities' adoption of blockchain technology is minimal. Thus, we need more support from empirical evidence, and the level of understanding could be higher. We observe a lack of strategies, and the approaches used are not comprehensive and adequate – with few exceptions.

2.5 Conclusions

In the following years, many countries will likely observe a widespread attempt to implement blockchain technology-based projects that can have a tangible impact on people's lives. Governments cannot help but consider the need to update their organizational models by adapting them to the evolution of society and business models [51].

The policymaker must design and implement appropriate policies and regulations that foster innovation and competition while preventing abuse and harm. It must also engage with various stakeholders, such as developers, users, researchers, and civil society organizations, to promote dialogue and collaboration on blockchain-related issues. The policymaker has the responsibility to shape the future of blockchain technology in a way that is democratic, inclusive, and sustainable. Some elements to consider when implementing blockchain technology are:

- Governments should consider leading the process in strict cooperation with businesses, users, and other stakeholders; considering the disruptive impact that blockchain could have on people, culture, and society, we are talking about the need to establish a new "smart" social contract. A smart social contract is an agreement between parties enforced by blockchain technology and can facilitate cooperation, coordination, and trust among them. A smart social contract can also reflect the values and goals of the society that adopts it, such as fairness, transparency, accountability, and participation.
- Accordingly, the implementation should be gradual and shared; the transition to blockchain technology should not be abrupt or imposed but relatively incremental and participatory. The implementation should involve consultation and feedback from different stakeholders, as well as education and awareness-raising campaigns to inform the public about the benefits and risks of blockchain technology. The implementation should also be adaptive and responsive to changing needs and circumstances, allowing for adjustments and improvements.
- Considering that research in this field is rapidly changing, and much knowledge is already obsolete, policymakers should consider a short implementation timeframe. Adopting methodologies and architectures older than three or four years could be dangerous and inappropriate for the current context. Also, many current challenges could have been better managed with a blockchain infrastructure (e.g., energy shortage); hence, governments are already late; this means that policymakers should not delay or postpone blockchain technology adoption but act swiftly and decisively. Policymakers should keep abreast of the latest developments and innovations in blockchain research and practice and adopt the most suitable and effective solutions for their specific contexts. Policymakers should also anticipate and address potential challenges from using blockchain technology, such as security threats, ethical dilemmas, or social resistance.
- Country's productive, organizational, and technological structure should be ready to support this change. If digital infrastructures are unavailable, policymakers should evaluate more investments. This would also impact acceptability, trust, and accessibility reducing the digital divide,

organizational readiness, scalability, and usability. This means policymakers should ensure that the necessary digital infrastructures are available and accessible for implementing blockchain technology. This includes reliable internet connectivity, adequate computing power, secure data storage, user-friendly interfaces, and interoperable standards. Policymakers should invest in developing and upgrading these infrastructures and providing digital literacy training for users. This would enhance the acceptability, trustworthiness, and accessibility of blockchain technology and reduce the digital divide between those who can and cannot use it. This would also improve the organizational readiness, scalability, and usability of blockchain applications, making them more efficient and effective.

- When the policymaker decides to implement blockchain technology, more technical evaluation is needed (e.g., permissioned/permissionless; minimizing energy consumption; maximizing performance and efficiency). Policymakers should conduct a thorough technical assessment of blockchain technology's diverse types and features and choose the most appropriate ones for their specific purposes and goals. For example, policymakers should decide whether to use a permissioned or permissionless blockchain, depending on the level of trust and control they want to have over the network participants and transactions. Policymakers should also consider minimizing blockchain technology's energy consumption and environmental impact using more efficient consensus mechanisms or renewable energy sources. Policymakers should also consider maximizing blockchain technology's performance and efficiency by optimizing network speed, security, scalability, and reliability.
- The definition of a legal framework is needed. A legal or regulatory framework constitutes a legal basis for cooperation between people and organizations. Rules would also impact interoperability, trust, and accessibility. Policymakers should establish a clear and consistent legal or regulatory framework for blockchain technology that defines the rights and obligations of all parties involved and the mechanisms for dispute resolution, enforcement, and compliance. The legal or regulatory framework should also facilitate interoperability, trust, and accessibility of blockchain technology by ensuring compatibility and coordination among different systems, standards,

and jurisdictions, enhancing transparency and accountability of network operations, and protecting the privacy and security of data and transactions.

The implementation strategy of blockchain requires that decisions be made considering the characteristics of local communities and the specific needs of each area and sector. The policymaker can encourage the development of blockchain solutions by the citizens in several ways. One of them is to provide monetary incentives, such as grants, subsidies, tax breaks, or rewards, for those who create or adopt blockchain-based applications that address social or environmental issues. Another way is to foster private initiative and innovation by creating a supportive regulatory framework and a collaborative ecosystem that allows blockchain developers to tailor their solutions to the local needs and characteristics of the communities. By doing so, the policymaker can stimulate the growth of a decentralized and participatory economy that leverages the potential of blockchain technology.

Given the potential benefits and extraordinary challenges, it is not surprising that the most promising proposals come from developing countries, which are not required to enforce a disruptive change to the habits and costumes of citizens. Also, these countries are still in time to base their certification, public registries, and transaction systems on more efficient and quicker infrastructures than the outdated bureaucracy we can find in advanced countries [105, 77].

Nevertheless, we can observe a remarkable effort to unlock the transformative power of blockchain in North America and Europe. For example, the United States, United Kingdom, Netherlands, Sweden, China, and European Union, announced their intention to evaluate and explore potential applications. We can already observe experimentation at the local level.

CHAPTER 3: THE EUROPEAN UNION'S SUPPORT AND FACTORS INFLUENCING BLOCKCHAIN INNOVATION: A PANEL DATA ANALYSIS

3.1 Background: The European Union's Support for the Adoption of Blockchain Technology

The efforts made by the European Union to address the research and development of blockchain technology are remarkable. According to the JRC report by Allessie et al. [76] and commissioned by the European Commission, it is stated that *"Establishment of reference blockchain infrastructure composed of certified, independent nodes to host public services has already become a policy priority for the EU"*.

In 2017, all the twenty-seven EU Member States and five EFTA countries signed a joint ministerial declaration in Tallinn about the need to work together to build an efficient and secure environment for digital public services to make steps towards the full deployment of the Connected Digital Single Market [106].

In 2018, the 27 EU countries, plus Norway and Lichtenstein[13], created the European Blockchain Partnership (EBP) as a follow-up of the joint declaration and intending to accelerate the implementation of blockchain-based services in the public sector while improving the delivery of digital services enforcing regulations, and ensure efficiency in legal compliance [107, 108].

The signatories recognized the potentiality of this technology for improving public services in Europe and creating new opportunities for society and the economy. They agreed to establish a joint infrastructure supporting cross-border digital public sector services. The agreement proposes to enhance cooperation among member states, the European Commission, the private sector, and academic institutions. It aims to develop interoperable frameworks for blockchain in Europe based on standardized solutions and governance models and foster research and innovation actions to address scientific barriers and future developments of blockchain technologies. Members share experiences, best practices, and key takeaways related to its implementation.

[13] The declaration was initially signed by 21 EU Member States plus the UK and Norway. Lichtenstein and the remaining EU Members have joined the initiative. UK is no longer a member of the EBP as the Withdrawal Agreement entered into force on February 1st, 2020.

The partnership builds on existing initiatives, such as the EU Blockchain Observatory and Forum launched in February 2018 by the European Commission to boost blockchain innovation and diffusion of blockchain ecosystems in the EU to enhance Europe's role as a global leader in blockchain technology.

Accordingly, in 2019 the 29 EBP members and the European Commission founded the European Blockchain Services Infrastructure, which sets the objective of creating public services at the European level based on blockchain technologies, characterized by superior levels of security and privacy and fully compliant with the EU regulatory framework, which is an essential feature of a digital single market. The EBSI currently focuses on developing case studies that can be implemented in European architecture. The initial use cases were the following: notarization of documents, European Self-Sovereign Identity, Diplomas management, and Trusted data sharing. The results are promising; some education and social security applications are already available [109].

The EBP and the EBSI have been supported through the European Blockchain Pre-Commercial Procurement (PCP), which funds the development and testing of blockchain solutions based on the EU legal framework[14]. On top of that, and more broadly, the European Commission has been supporting and providing grants and prizes to blockchain projects and research through the Digital Europe Programme, which is part of the long-term framework programmes funded by the EU budget, such as the 7th Framework Programme for Research and Innovation (FP7, 2007-2013)[15] – which funded only a couple of projects in 2013 -, the Horizon 2020 Programme (H2020, 2014-2020)[16], and its successor the Horizon Europe Programme (HEUR, 2021-2027)[17], and more programs are ongoing or under preparation[18].

[14] https://digital-strategy.ec.europa.eu/en/news/european-blockchain-pre-commercial-procurement

[15] https://wayback.archive-it.org/12090/20191127213419/https:/ec.europa.eu/research/fp7/index_en.cfm

[16] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020_en

[17] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

[18] https://digital-strategy.ec.europa.eu/en/policies/blockchain-funding

3.2 The European Union Framework Programmes: Data and Results

The main objective of the EU Framework Programme is to strengthen *"science and technology in the European Union through increased investments in highly skilled people and cutting-edge research promoting the EU's industrial competitiveness and its innovation performance achieving the EU's strategic priorities, such as the Paris Climate Agreement, and addressing global challenges that affect the quality of our daily lives."*[19]

The Horizon 2020 was the first EU Framework Programme to provide significant funding to research and innovation on blockchain projects. The program initially covered 2014-2020 and was extended as usual with the new Horizon EU 2021-2027 Framework Programme. The two programs are essentially a re-proposal of each other, and some main features characterize both.

The amount of resources available for Horizon 2020 was around eighty billion euros, while for Horizon Europe, the resources have been increased to more than ninety-five billion. The main differences between HEUR compared to H2020 are as follows:

- It allows grants and direct support for laboratory research projects that aim to become startups.
- HEUR includes, among the projects eligible for funding, general research proposals by academic institutions that cover several countries and aim to analyze the daily issues of citizens.
- HEUR offers free access to publications, data, and research data management plans.
- The simplified access to the HEUR Programme reduces the administrative burden on beneficiaries.
- Finally, HEUR expands potential participants for the EU co-programs or co-funds, including more eligible organizations and individuals from industry, civil society, and funding foundations.

H2020 and HEUR can provide funding to public bodies, research organizations, private for-profit entities, start-ups and SMEs, universities, and higher or secondary

[19] https://www.pnoconsultants.com/grants/horizon-europe/

education establishments. All residents from the twenty-seven EU member states are eligible for funding, and additional countries are associated with the Programme[20].

They both aim to provide grants and prizes to research projects, solutions for businesses, practical innovations, and technological developments in three main pillars: Excellent Science, Industrial Leadership, and Societal Challenges.

The classification and distribution among fields of application have slightly changed from H2020 to HEUR:

- Pillar I supports cutting-edge research projects that researchers themselves define and lead through the European Research Council (ERC), including research collaboration and research infrastructures through the Marie Skłodowska-Curie Actions (MSCA).
- Pillar II supports research related to societal challenges collected in six clusters:
    - Health
    - Culture Creativity and Inclusive Society
    - Civil Security for Society
    - Digital Industry and Space
    - Climate, Energy, and Mobility
    - Food, Bioeconomy, Natural Resources, Agriculture, and Environment

  Resources can also be issued for programs and projects supporting the EU 2030 targets: climate change adaption; fight against cancer; healthy oceans,

[20] Residents in the following countries are entirely eligible: Albania, Armenia, Bosnia and Herzegovina, Faroe Islands, Georgia, Iceland, Israel, Kosovo, Moldova, Montenegro, North Macedonia, Norway, Serbia, Tunisia, Turkey, and Ukraine. A transitional arrangement governs Morocco's participation. New Zealand entities are eligible only for Pillar II, "Global Challenges and European Industrial Competitiveness". United Kingdom residents were entirely eligible during the H2020 Programme without restrictions. After Brexit, the UK participates in all parts except the Europe Innovation Council Fund, which provides investment through equity or other repayable forms. Many other countries are eligible but subject to several restrictions and conditions.
Collaboration with residents in Australia, Canada, China, and the United States is allowed without financial charges.
More information at the following website: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/common/guidance/list-3rd-country-participation_horizon-euratom_en.pdf

seas, coastal and inland waters; climate-neutral and smart cities; soil and food health. Pillar II includes some activities of the Joint Research Center.

- Pillar III is managed by the European Innovation Council (EIC) and promotes integration and innovation through the European Innovation Council Accelerator Programme and the European Institute for Innovation and Technology (EIT).

The HEUR program, which started in 2021, has funded 5593 projects for a total of €16.87 billion, while the H2020 program, which ran from 2014 to 2020, has funded 35380 projects for a total of €68.29 billion. These programs cover a wide range of topics and types of projects, from health and environment to social sciences and humanities, and involve thousands of participants from different countries and sectors. Given the vastness and variety of projects offered by the HEUR and H2020 programs, the cataloging would require a complexity of work that far exceeds the objectives of the paper, so we preferred to evaluate only the projects that refer to the adoption of blockchain technology. By limiting our analysis to blockchain-related projects, we were able to provide a more in-depth and comprehensive overview of the current state of the art and the future prospects of this emerging field. The projects that are not related to blockchain may have different definitions, classifications, and indicators than the projects that are related to blockchain, making it difficult to compare them. For example, projects that are not related to blockchain may have different types of participants, funding schemes, outputs, and impacts than projects that are related to blockchain, which may reflect different objectives, priorities, and contexts. Therefore, by focusing on blockchain-related projects, we were able to ensure a more consistent and coherent analysis of the data.

It is argued that the impact of the H2020 and the HEUR on research, development, and adoption of blockchain solutions can be estimated through the database of the Community Research and Development Information Service (CORDIS) of the European Commission[21], which collects data and information on all the projects funded under both programmes. To the best of our knowledge, this is the first attempt to perform such an exercise in a rather comprehensive way.

The data source has some limitations that affect its comprehensiveness and representativeness of blockchain adoption. The main limitations are:

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[21] https://cordis.europa.eu/en

- It only considers grants, which are one type of public funding instrument. Other types of public funding, such as loans, guarantees, subsidies, tax incentives, etc., that may also have an impact on blockchain adoption, are not captured by the data source.
- It only considers the public funding source from the EU level and does not capture the demand for blockchain technology that is not funded by the EU, which may constitute a significant or increasing portion of the market. Other sources of public funding, such as national, regional, or local governments, that may also provide support to blockchain projects, are not captured as well. Hence, the data source may omit some important applications or sectors where blockchain technology is used or demanded, but not funded by the EU.
- It only considers the geographical limitation of the EU and associated countries, which is the scope of the H2020 and the HEUR. Other countries or regions outside this domain may also adopt blockchain technology but are not captured by the data.
- It does not account for the supply of blockchain technology, which may depend on factors such as private investments, technological capabilities, innovation ecosystems, etc. The data may not reflect the true availability or quality of blockchain technology or its competitiveness in the global market.

However, the data has some advantages that support the choice, despite its limitations. First, CORDIS is the largest public funding database for projects in research and innovation in the EU. It covers a wide range of topics and sectors, including blockchain technology, which is one of the key digital technologies supported by the program. Therefore, it reflects the EU's strategic priorities and investments in blockchain technology, which are likely to have a significant impact on its development and diffusion. This addresses the limitation of not capturing other sources of public funding, as the H2020 and the HEUR programs are the most relevant and influential at the EU level.

Second, the database provides consistent and comparable information on the project's characteristics and outcomes, which allows for a rigorous and robust analysis. It includes information on all the projects funded by the EU that involve blockchain technology, either as a main or a secondary component. The data source provides detailed information on the project's objectives, partners, budget, duration, and expected outcomes. Moreover, the data source is publicly available and regularly updated on the EU's official website, which ensures transparency and accountability. Although the limitation of not capturing the demand or supply of blockchain technology that is not funded by the EU, the data cover a large and diverse sample of blockchain projects that represent different applications and sectors where blockchain technology is used or demanded.

Third, the data allow us to measure the demand for public funding on blockchain innovation, which is one of the main research questions of the thesis. It can also allow controlling for other factors that may influence blockchain adoption, such as country characteristics, sector characteristics, and time trends, and enables to assess the quality and availability of blockchain innovations in the EU.

It is not intended to imply that public funding by the EU is the only or the best way to study blockchain adoption, but rather to focus on one specific aspect of it that has not been explored in depth in the literature. Other factors may stimulate the production and adoption of blockchain technology, such as private investments, market demand, regulatory frameworks, social norms, etc. However, these factors are more difficult to measure and compare across countries and sectors, and they may require different methods, and data is still not available. Therefore, it is beneficial to limit the scope of the analysis to this source, which provides a well-defined and observable variable that can be easily quantified and analyzed.

To begin with, in order to understand the scope of financial support that the European Union provides through its development programs, all data related to blockchain projects have been collected; then, the information has been gathered in a dataset that identifies the main characteristics of each project, including the text used to describe each and all projects.

To this end, the preliminary step was to design a search protocol selecting the most appropriate keywords and considering additional filters to eliminate irrelevant content. Thus, we included all projects that have, in their description, keywords, or other information, one of the following words: "blockchain", or "block chain", or "smart contracts"[22]. As of May 4th, 2023, the results were 550 out of over 40,000 projects.

[22] Search protocol: contenttype='project' AND ('Blockchain' OR 'Block chain' OR 'Smart Contracts')
550 results

Successive refinements were needed since some projects do not refer to blockchain applications or blockchain research but cite blockchain in the project description only as an *alternative* technology. After reading the description of all projects and having established which projects are eligible for the research goal, those projects lacking the essential component of being directly or indirectly blockchain-related have been eliminated from the dataset. The final list includes 336 projects[23].

The 279 projects under the H2020 programme have an initial date of January 1st, 2015, and cover all projects up to December 31st, 2021; on the other hand, the fifty-seven projects under HEUR have initial dates ranging from January 1st, 2022, up to date.

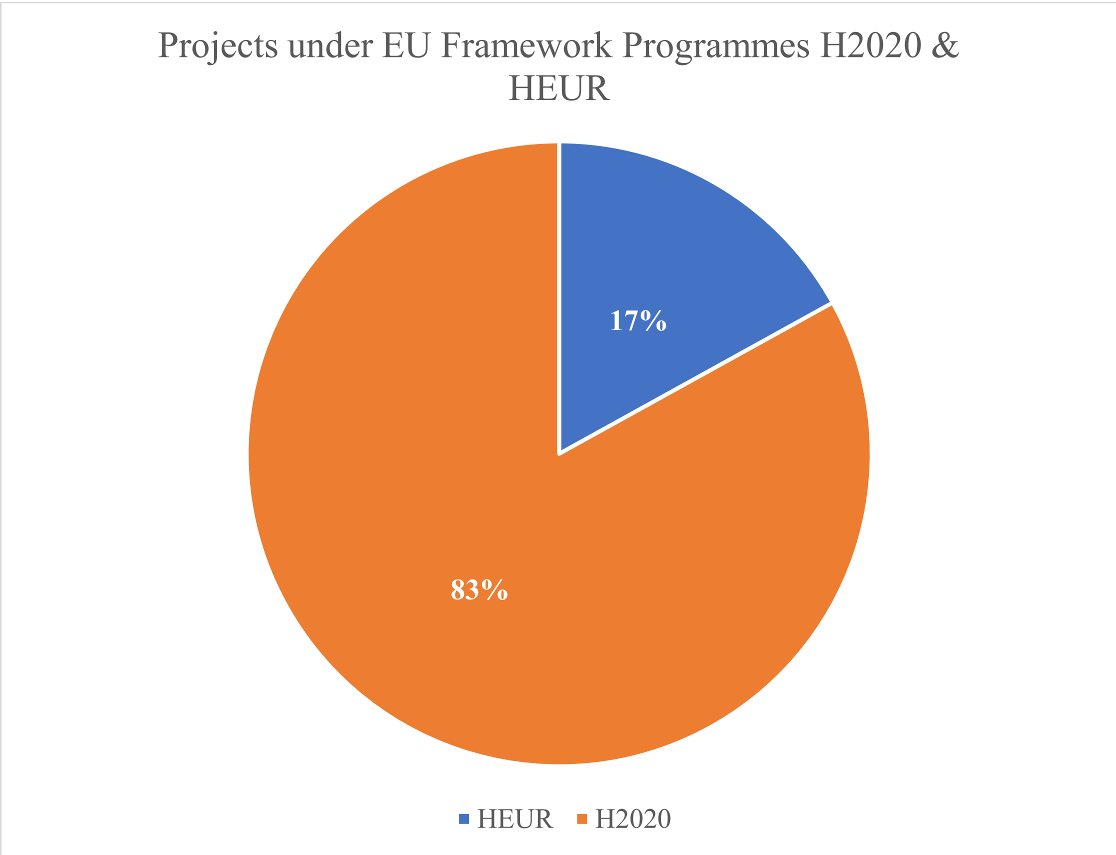

Figure 16 - Projects under the EU Framework Programmes, own elaboration. Source: CORDIS (2015-2023)

[23] Two projects from the FP7 programme have been deleted since they hardly fit into the H2020 and HEUR classifications and cannot be easily categorized into the dataset.

According to the collected figures, the total granted by the European Union amounts to €1,393,717,931.66 out of a total investment of €1,774,563,100.81. Therefore, the additional capital mobilized amounts to €380,845,169.15, with a ratio of about 1:4 compared to the grants allocated (21% of the total).

More in detail, the projects can be classified according to their start date. Expectedly, only a limited number of projects (eight) were funded in 2015, the beginning year of the H2020 program. The numbers increased considerably in the following years, with 12 projects in 2016, 27 in 2017, 62 in 2018, and 99 in 2019. In 2020 we observed a slowdown, presumably due to the COVID-19 pandemic outbreak: only 53 projects were launched that year. The downward trend persisted in 2021, with eighteen projects, while the numbers resumed growing in 2022 (34 projects) and 2023 (23 projects as of May 4). The completion dates of the projects vary over a broader range from 2017 to 2028.

The upward peak was achieved in 2019 with €392 million in grants, while the lowest results were recorded in 2015 (€43.3 million), 2016 (€51.7 million), and 2021 (€80.6 million). Overall, the trend follows the same pattern as the number of projects, as shown in the following graph.

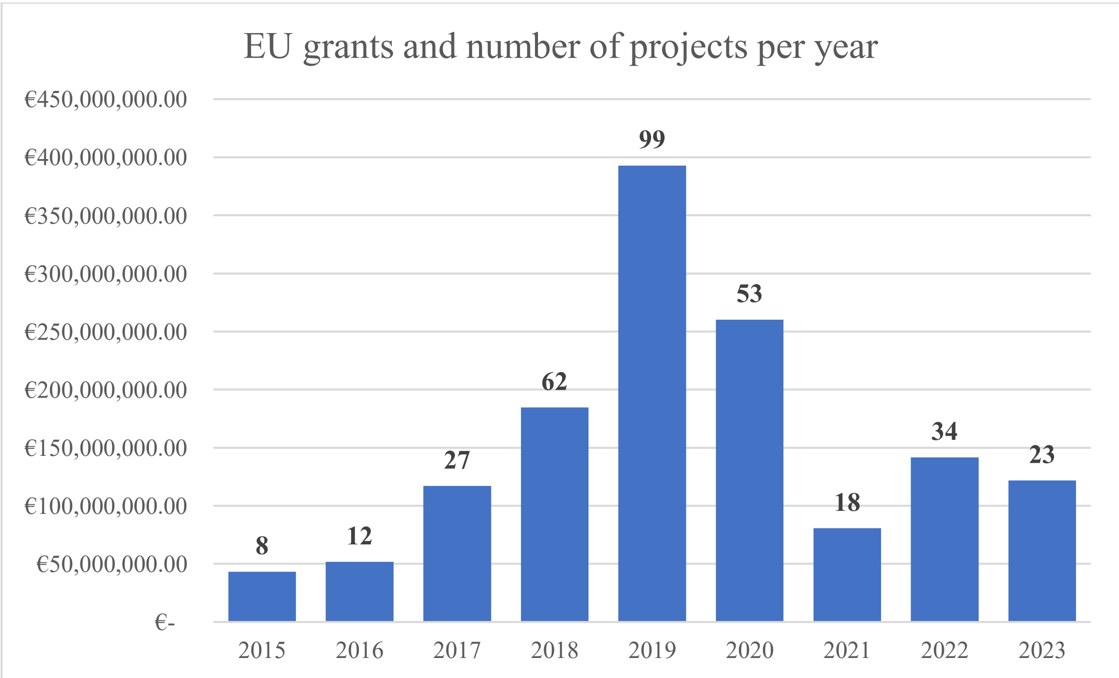

Figure 17 - EU grants and the number of projects per year, own elaboration. Source: CORDIS (2015-2023)

The classification by sector was done considering the project's final goal. In conclusion, we can identify the following macro-classifications:

- Arts, Culture, and Social Media (16)
- Business and Management (12)
- Cybersecurity and Data protection (34)
- Data management and registries (25)
- Energy (37)
- Financial sector (16)
- Food, Bioeconomy, Natural Resources, Agriculture, Environment, Sustainability (47)
- Healthcare (23)
- ICT (30)
- Industry & Manufacturing (18)
- IoT (16)
- Public and social services (19)
- Research and Education (9)
- Tracking and Supply Chain (10)
- Transport, Mobility, and Smart Cities (24)

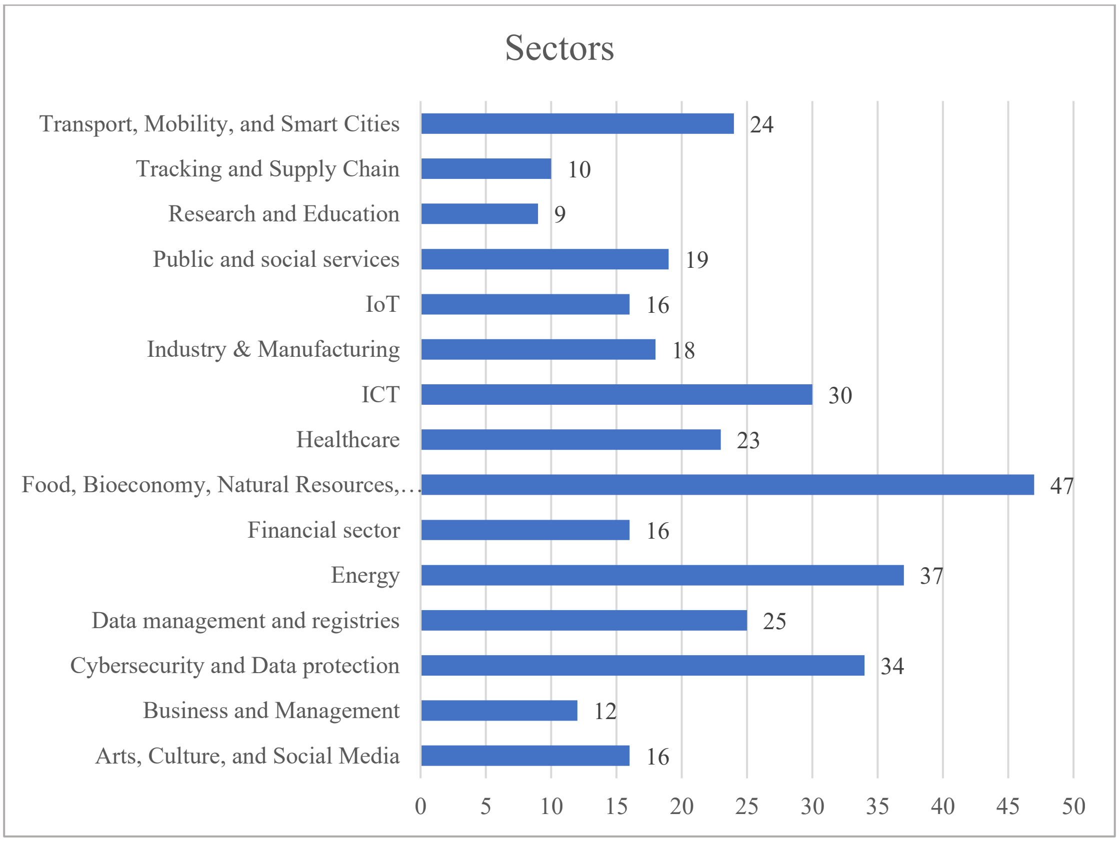

Figure 18 - Sectors, own elaboration. Source: CORDIS (2015-2023)

These data highlight how blockchain is a cross-cutting theme across multiple sectors. In addition, although it is evident that there are more projects related to ICT and Cybersecurity topics, which together exceed sixty observations, it is surprising that there are so many projects related to Food, Bioeconomy, Natural Resources, Agriculture, and Environment Sustainability, with forty-seven projects. Less relevant - also for the nature of H2020 and HEUR programmes - is the number of more general research projects referring to the educational sector. It is also worth mentioning that there are as many as thirty-seven projects on Energy.

Regarding the recipients, the overall number of participating organizations exceeds 2,000 units. Accordingly, the projects can also be sorted by the type of coordinating organization and the country of residence. However, it is frequent to have cross-country projects where tens of entities among the private sector, public bodies, and research institutions participate in the same project. So, for each project, the range of participating entities varies from one to over one hundred in a couple of observations. As many as 250 projects are cross-country, while only eighty-six have single-country recipients.

Looking at the coordinating organization, 103 projects were requested by Higher or Secondary Education Establishments, 157 by Private for-profit entities, sixty-five by Research Organizations, only six by Public bodies, and the last five by other types of organizations (foundations or solidarity entities).

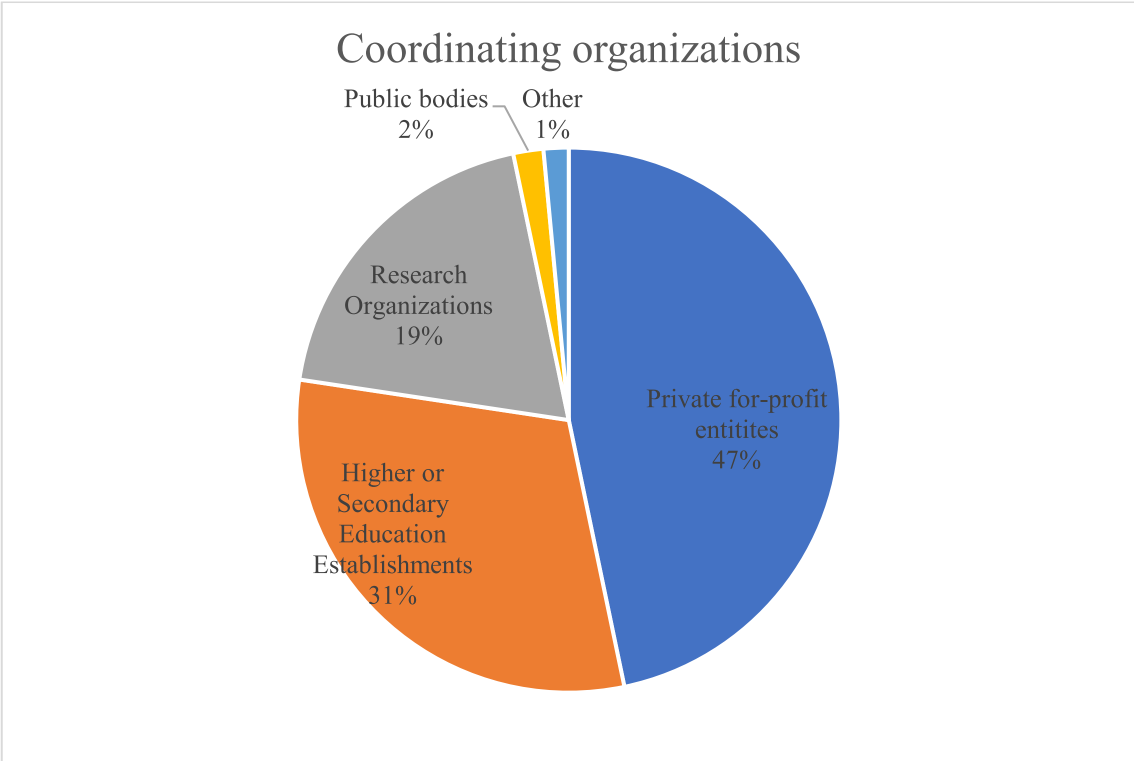

Figure 19 - Coordinating organizations, own elaboration. Source: CORDIS (2015-2023)

As mentioned, the countries participating in the initiative go far beyond the boundaries of the European Union. Therefore, it is unsurprising that countries like the UK, Switzerland, Serbia, Turkey, Norway, and Israel have achieved excellent results. Contributions to residents in North Macedonia, Egypt, Ukraine, Moldova, Bosnia-Herzegovina, Montenegro, and Georgia, have been included, while numerous African countries have been involved in one specific project. Organizations residents in Canada, the USA, China, Australia, Singapore, and Colombia also participated in the projects without receiving contributions.

The country that received the highest number of contributions is Spain, with about 178 million euros, followed by Germany (156M), Italy (152M), Greece (141M), and the

Netherlands (81M). In terms of projects in which a country is involved through the resident organizations, Spain once again prevails (198 projects), followed by Germany (159), Italy (147), Greece (142), Belgium (116), and then followed by France and UK (both with 112) and the Netherlands (108). The remarkable result of Cyprus, with 39.5M in 58 projects, and Luxembourg, with 30.7M in 39 projects, is worth to be mentioned.

However, the same data can be weighted for country size by dividing the numbers by the population size. The results change considerably considering the amounts weighted for the number of inhabitants. In this case, access to resources is particularly beneficial for Luxembourg (48.11 euros per inhabitant) and Cyprus (31.78 per inhabitant), followed by Greece (13.58), Estonia (10.50), and Slovenia (7.87). Among the worst, we can find Turkey (0.14), Slovakia (0.28), and Hungary (0.48). The results do not differ much in the number of projects. The three major countries (Germany, France, and Italy) significantly worsen their position in both cases. The data are summarized in the following graphs.

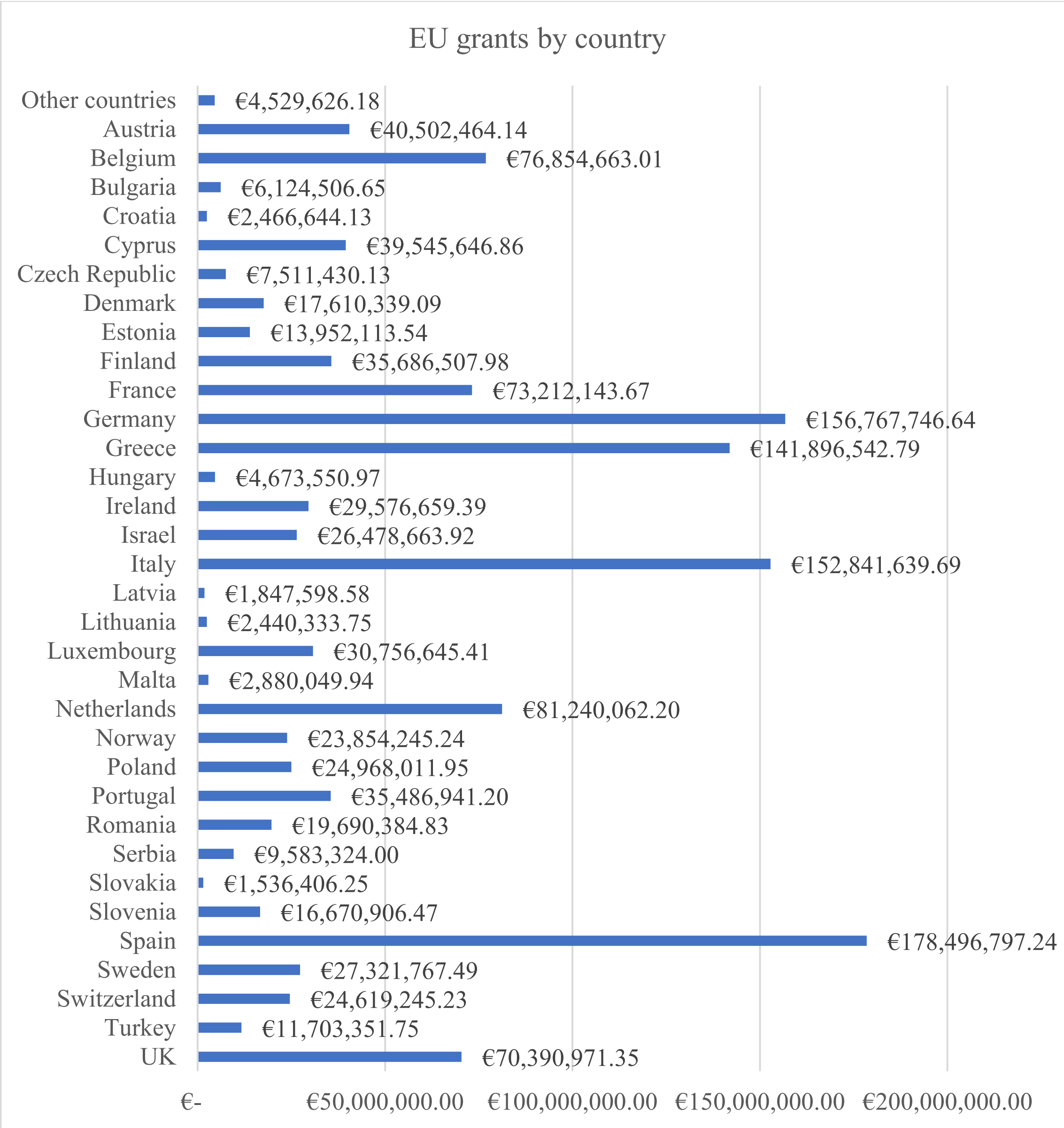

Figure 20 – EU grants per country, own elaboration. Source: CORDIS (2015-2023)

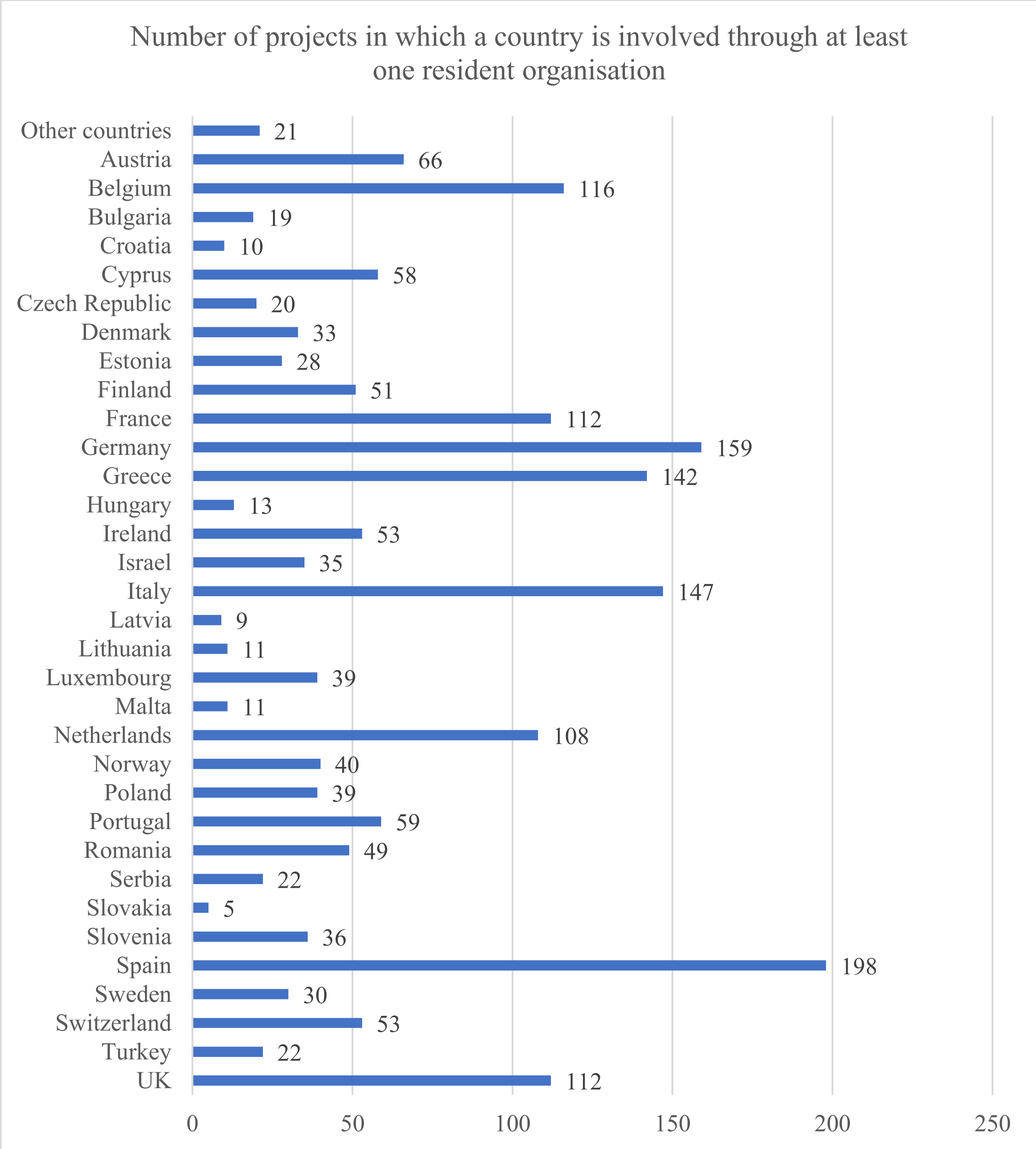

Figure 21 – Number of projects in which a country is involved through at least one resident organization, own elaboration. Source: CORDIS (2015-2023)

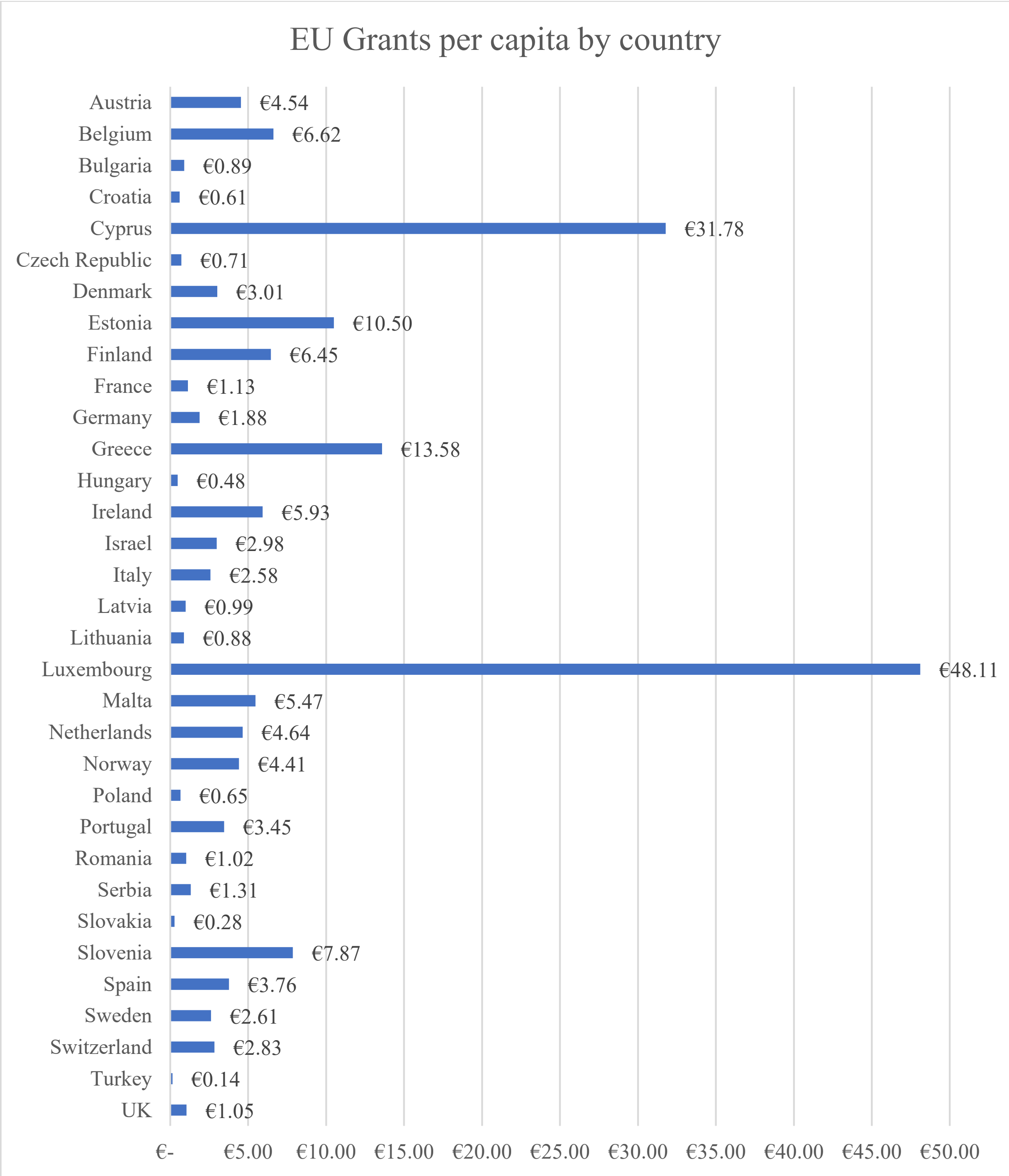

Figure 22 - EU grants per capita by country, own elaboration. Source: CORDIS (2015-2023)

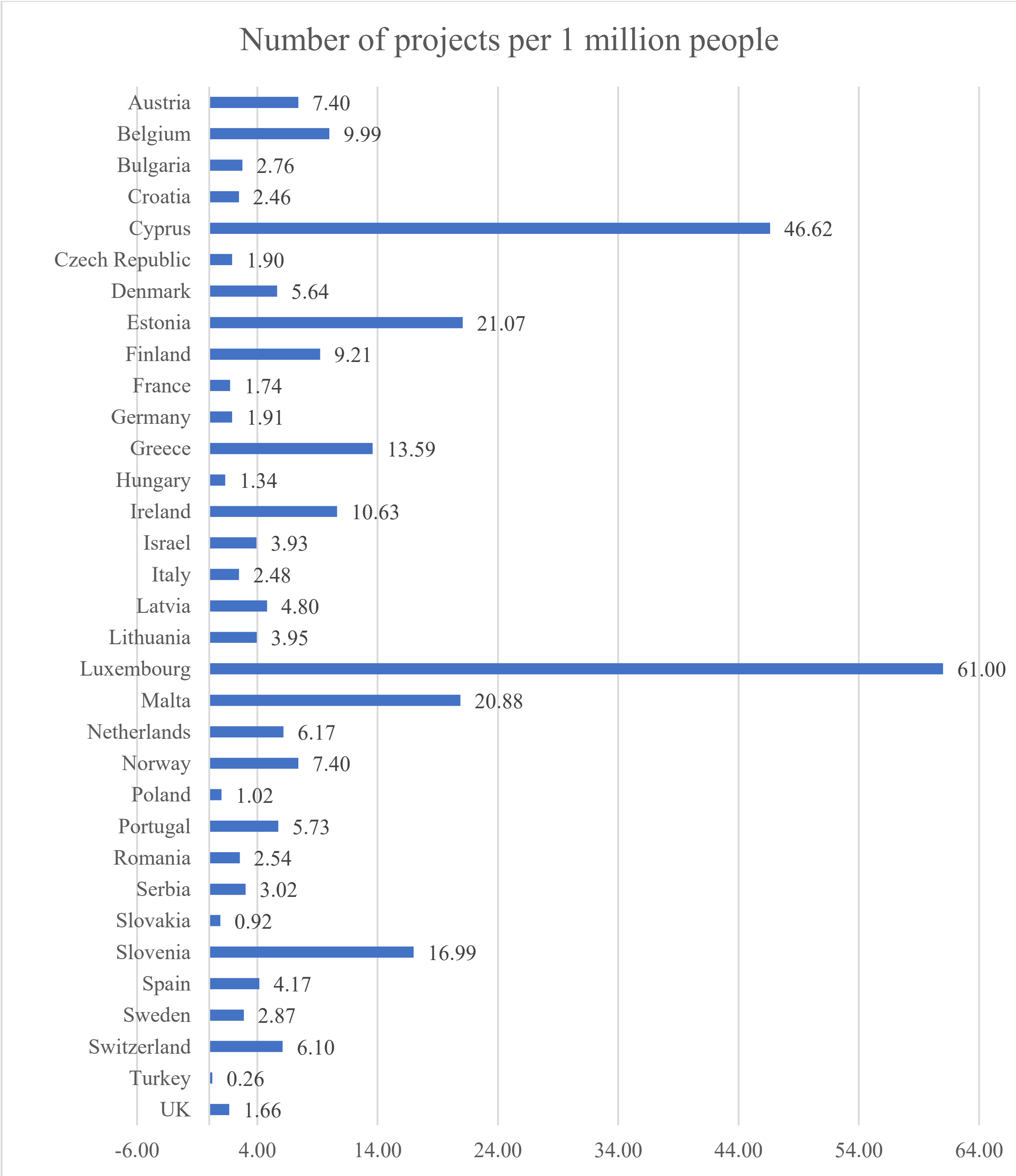

Figure 23 – Number of projects per one million people by country, own elaboration. Source: CORDIS (2015-2023)

3.3 Main Factors Influencing Blockchain Investments: A Panel Data Analysis

3.3.1 Objectives

The causal effects of structural factors on the number of EU grants provided to residents within each country are of utmost interest since they can offer oversight on the key drivers affecting the decisions of firms, citizens, and institutions to seek funding for the development of blockchain solutions. Hence, in turn, the extent to which it is available to citizens. Put differently, based on the theoretical framework and research questions of the previous sections, in this section, the study aims to investigate the determinants influencing the (successful) demand for grants for blockchain-related projects from organizations resident in European Union members and associated countries accessing funds from the EU framework program. Since funds are allocated on a competitive basis, we deem that the funded projects represent the more efficient use of resources in this field. More in detail, the study aims to:

- Investigate the relationship between the income level and the grants for blockchain-oriented initiatives.
- Analyze how the level of technological development influences the attitude toward innovation in blockchain within a country.
- Assess how the quality of public services affects the capability and willingness to provide new blockchain solutions.
- Examine the effect of social and demographic variables on the volume of investments directed to blockchain adoption.
- Measure the impact of education on blockchain research and development.

3.3.2 Selection of the Independent Variables

In principle, factors affecting whether to invest in blockchain solutions can have an ambiguous impact. For the sake of illustration, we can categorize these factors into the following groups:

- Demographic factors. Due to the high level of innovation that this technology entails and, especially, its disruptive effect on the interactions among agents in a social tissue, it is hypothesized that younger populations may be more interested in applying for incentives for blockchain projects. Conversely, aging countries typically present more inflexible systems, which demand updates and adjustments to modern technologies. Consequently, the demand for innovation conflicts with the resistant attitude of older societies, for which enterprises may find it beneficial to use grant resources rather than investing their capital in risky solutions that are still far from conclusive. That said, in order to detect the overall effect, we will investigate the relationship between the population size of a country and the number of grants per capita that the system can collect. The effect of the share of the young population (under 25) will be tested separately.

- Social factors. One of the critical elements for understanding investment dynamics is undoubtedly the population's propensity toward innovation. This propensity could be higher in countries with elevated levels of social progress, already used to implementing innovative solutions, and willing to embrace unexplored trends. On the other hand, it would not be unreasonable to think that, in the presence of lower levels of social development, there is a need to enhance the commitment to improve the existing infrastructures and the transaction and certification systems to foster the acceleration of the process towards the futuristic ICT societies. In this case, therefore, the impacts could be ambivalent too.
- Educational factors. As already stated, blockchain technology's high technological content requires residents to manage and handle the tools to deepen the research on the topic. This depends, essentially, on the ability of research organizations and higher education institutions to invest in research and development but also on the quality of educational structures, especially in scientific disciplines. A high number of graduates or the diligent work of researchers could, in this case, increase the number of investments in blockchain. On the other hand, the high demand for resources in countries that struggle to innovate could lead countries with lower schooling rates or research levels to look for external sources to collect the necessary funds for risky investments.
- Institutional and political factors. They pertain to the regulatory, legal, and fiscal framework that regulates the use and development of blockchain solutions, as well as the degree of trust and acceptance by the stakeholders involved. Blockchain is a technology that aims to increase the level of trust, transparency, and quality of bureaucratic systems and strengthen the tools of interaction between public administrations and citizens. The quality and efficiency of public services, in this case, would motivate investments in blockchain according to two directions: on the one hand, more efficient systems tend to seek transparent and effective solutions; on the other hand,

systems that present shortcomings or inequalities require solutions that are changing for the already deteriorated relations with the citizens.

- Economic factors. The impact that the economic solidity of a country can have is less evident. Countries with higher income and wealth have more resources to invest in research and development, but on the other hand, they access grant resources less frequently. Conversely, low-income levels compel organizations to seek additional funds, especially for investments with a considerable risk of failure. Economic factors also pertain to the cost-benefit, the return on investment, and the risk associated with the blockchain projects, as well as the market opportunities and competition. In this case, the initial lack of funds - related to the shortage of infrastructure and technology - could reduce the willingness to innovate and, consequently, the demand for new resources.
- Technological factors. Closely related to social and economic factors, technological factors pertain to the level of innovation, maturity, and security of the existing infrastructure, the perceived benefits of blockchain solutions, and compatibility with the existing grids and systems. Technological factors also include the capability and willingness of enterprises and organizations to adopt and implement blockchain solutions, as well as the challenges and barriers, internal and external, that can impede the process of change. The technological development of a country would facilitate the implementation of blockchain technology downstream, as it can be easily adapted to the existing infrastructures. Still, it would be a disincentive upstream, as there is no need to modernize already modern infrastructures. On the contrary, in contexts with low technological development, the high implementation and delivery cost discourages searching for innovative solutions. Still, it is attractive upstream, as it can positively affect productivity and efficiency.

Since the impact of selected factors is far from being clear-cut, the empirical investigation in this field is of pivotal interest both for academics and practitioners. Therefore, this study will empirically examine how several factors affect the decision to invest in blockchain solutions in Europe and associated countries. Indeed, it has been argued that these factors can produce different outcomes depending on the level of development, innovation, and social progress of each country. As a result, since, as aforementioned, there is no clear-cut answer to whether blockchain technology is a driver or a consequence of development, this study will aim to provide a tentative answer concerning both the statistical significance and the sign of selected social and economic indicators. Indeed, analyzing each case's particular circumstances and goals is crucial.

To this end, the following variables have been selected:

- GDP per capita (*gdp_pc*) is an economic indicator measuring a population's average income level. It reflects the availability of resources for research and development, the demand for products and services, and the level of entrepreneurship in a country. We expect it positively affects the demand for grants as it reflects firms' and consumers' spending and investment capacity. The source is the World Development Indicator, a World Bank dataset containing data on various aspects of countries' economic and social development. The period considered is 2013-2021; the data are expressed in thousands of US dollars [110].
- Total population (*pop*) is a demographic indicator that measures the size of a country. This variable could affect the demand for innovation grants as it reflects a country's market size and demand for innovative products and services. However, at first sight, a larger population implies lower grants per capita, probably due to the ability of smaller countries to maximize applications for incentives. Thus, we expect it positively affects the total amount of grants and negatively affects the per capita amount, although it should be more reasonable to consider it neutral. The source is the United Nations - World Population Prospects, a dataset that provides estimates and projections of population size, age structure, fertility, mortality, and migration for all countries and regions. The period considered is 2013-2021; the data are expressed in millions [111].
- Access to ICT (*ict*) is an indicator of digital development and connectivity. It measures the availability and affordability of information and communication technologies such as Internet connection, electronic devices, mobile phones, and broadband in a country. The level of digital infrastructure and access to information and communication could enable and facilitate innovation in a country. Its impact should be positive since access to ICT depends on the level of innovation, maturity, and security of the existing infrastructure, the perceived benefits of blockchain solutions, and compatibility with the existing systems. It also includes the capability and willingness of citizens to

adopt and implement blockchain solutions, as well as the challenges and barriers, internal and external, that can impede the process of change. The source is the Social Progress Imperative, an organization that produces the Social Progress Index, a comprehensive measure of social and environmental performance covering multiple well-being dimensions. “Access to ICT” is a sub-component of the dimension of opportunity in the Social Progress Index, which captures the degree to which a country provides opportunities for personal choice, freedom, and social mobility to its citizens. The period considered is 2014-2022, and the data are expressed on a scale from 1 to 100, where higher values indicate better access to ICT [112].

- Population under 25 years old (*pop25*) is a demographic indicator that measures the proportion of young people in a population. This variable could affect the demand for grants as it reflects a country's potential human capital and innovation capacity. Its impact may be ambiguous; indeed, a younger population may be more interested in applying for incentives. Conversely, aging countries typically present more inflexible systems, which demand updates and adjustments to modern technologies. However, we expect the positive impact should outweigh the negative one since the innovative content of this technology requires a strong willingness among the population that usually is the highest among the youngest people. The source is the same as above, United Nations - World Population Prospects. The period considered is 2013-2021; the data are expressed as a percentage of the total population [111].
- Number of NEETs in percentage (*neet*) is an indicator of youth unemployment and social exclusion. As known, NEET stands for Not in Education, Employment, or Training and refers to young people who are neither studying nor working. This variable is a driver for the social challenges and needs that could be addressed by blockchain solutions in a country. NEETs may positively affect the amount of demanded grants since the country could be motivated to adopt new solutions for social and technological innovation. However, the lack of skills, resources, or opportunities could negatively affect investments in blockchain. We expect the sign to be negative since countries, where the young population is employed, receive a greater boost to innovate from this age group. This

indicator is a sub-component of the dimension of opportunity in the Social Progress Index, which captures the degree to which a country provides opportunities for personal choice, freedom, and social mobility to its citizens. The period considered is 2014-2022; the data are expressed as a percentage of young people aged 15-29 who are NEETs [112].

- Access to public services inequality (*pubservices*) is an indicator of social justice and equity. It measures how equally public services such as health care, education, water, and sanitation are distributed among separate groups of people in a country. Access to public services describes the level of participation of citizens. It is related to the efficiency and transparency of public service delivery. On the one hand, public services can improve the quality of life, well-being, and human capital of the population, which can, in turn, stimulate their creativity, productivity, and entrepreneurship. On the other hand, people who have lower access to public services may be more likely to pursue innovative ideas and projects and seek grants for innovation on blockchain as a way to fund them. In this sense, this variable could affect the demand for grants as it reflects the gaps and disparities that could be reduced by innovative interventions in a country. However, we expect the impact to be positive since the capacity to introduce innovations is extremely supported by efficient public services. It is a sub-component of the dimension of basic human needs in the Social Progress Index, which captures how well a country provides for its people's essential needs, such as nutrition, health, safety, and shelter. The period considered is 2014-2022, and the data are expressed on a scale from 0 to 4, where higher values indicate more inequality. [112].
- Number of citable documents per one thousand people (*citdoc*) is an indicator of scientific output and research quality. It reflects the level of research activity in a country and could positively affect the demand for innovation. A higher number of citable documents implies a more vibrant and dynamic academic environment, where new discoveries and insights are generated and shared. This can foster a culture of innovation and learning and encourage people to apply for grants for innovation on blockchain as a means to advance their research agendas. The source is the Social Progress Imperative. This indicator is a sub-component of the dimension of access to advanced

education, which captures the availability and quality of higher education in a country. The period considered is 2014-2022, and the data are expressed as the number of citable documents per one thousand people [112].

- Quality-weighted universities (*qualuniv*) is another indicator of higher education quality and research excellence. It may reflect the potential impact of the high-level educational system on the demand for grants. Higher-quality universities can attract more talented students and faculty, who can develop new applications and solutions using blockchain. This can create more demand for grants for blockchain adoption, as universities seek to fund their projects and collaborate with other stakeholders in the ecosystem. It is a sub-component of the dimension of access to advanced education in the Social Progress Index. It measures the number of universities within a country weighted by their ranking in international academic rankings. Since it strongly depends on the number of universities, it has been adjusted for the case of EU grants per capita, dividing it by the population size (*qualuniv_adj*). The period considered is 2014-2022; the data are expressed in points. It ranges from 0 to 350 for the first case and 0 to 11 for the second case [112].
- Government effectiveness (*gov*) is an indicator of institutional quality and governance performance, reflecting perceptions of the quality of public services, public authorities' independence and credibility, the absence of pressure, and the efforts to ensure transparency and freedom. It reflects how the quality and effectiveness of public services and policies can affect blockchain adoption. This variable could have a positive impact as it reflects the efficiency and accountability of public administration and the conduciveness of the policy environment for innovation in a country. The source is the World Bank Governance Indicators, a dataset that measures six governance dimensions for over two hundred countries and territories. The period considered is 2013-2021, and the data are expressed on a scale from 0 to 5, where higher values indicate better governance [113].

Table 11 shows the list of the independent variables, their categorization, and the source. Table 12 describes the rationale for the introduction of each variable, the transmission mechanism, and the expected impact and sign.

Variable	Factor	Source
GDP per capita (thousands of USD)	Economics	World Bank
Access to Information & Communications [0-100]	Technology	Social Progress Imperative
Population under 25 years old (%) [0-100]	Demography/Society	United Nations
NEET (%) [0-100]	Society/Economics	Social Progress Imperative
Access to public services inequality [0-4]	Institutions/Society	Social Progress Imperative
Citable documents (/1000 people) [0-6]	Education	Social Progress Imperative
Quality Weighted Universities (total [0-350]; adjusted [0-11])	Education	Social Progress Imperative
Government Effectiveness [0-5]	Institutions/Politics	World Bank

Table 11 – List of the independent variables

Variable name and label	Rationale for inclusion	Potential mechanism	Impact	Expected sign
GDP per capita (*gdp_pc*)	It reflects the availability of resources for research and development, the demand for products and services, and the level of entrepreneurship in a country.	Countries with higher income and wealth have more resources to invest in research and development but they access grant resources less frequently. Conversely, low-income levels compel organizations to seek additional funds, especially for investments with a considerable risk of failure.	Mixed	We expect it positively affects the demand for grants as it reflects firms' and consumers' spending and investment capacity.
Total population (*pop*)	This variable could affect the demand for grants as it reflects the country's market size and demand	A large population means more people can access incentives. Instead, for the per capita amount the impact is expected to be zero. However, preliminary data show that a larger population largely	Positive for the total amount of grants.	Positive for the total amount. Negative for the per capita amount.

	for products and services.	impacts the demand for grants, probably due to the ability of smaller countries to maximize applications for incentives.	Neutral for the per capita amount.	
Access to ICT (*ict*)	The level of digital infrastructure and access to information and communication could enable and facilitate innovation in a country.	It depends on the level of innovation, maturity, and security of the existing infrastructure, the perceived benefits of blockchain solutions, and compatibility with the existing systems. It also includes the capability and willingness of citizens to adopt and implement blockchain solutions, as well as the challenges and barriers, internal and external, that can impede the process of change.		
Population under 25 years old (*pop25*)	This variable could affect the demand for grants as it reflects a country's potential human capital and innovation capacity.	A younger population may be more interested in applying for incentives. Conversely, aging countries typically present more inflexible systems, which demand updates and adjustments to modern technologies.	Neutral for the per capita amount of grants.	Positive. Due to the high level of innovation carried on by this technology, we expect that the willingness to adopt blockchain solutions will be extremely high among the youngest people.
Number of NEETs in percentage (*neet*)	This variable is a driver for the social challenges and needs that could be addressed by blockchain solutions in a country.	NEETs may positively affect the amount of demanded grants since the country could be motivated to adopt new solutions for social and technological innovation. However, the lack of skills, resources, or opportunities could negatively affect investments in blockchain.	Positive	We expect the sign to be negative since countries, where the young population is employed, receive a greater boost to innovate from this age group.
Access to public services inequality (*pubservices*)	Access to public services describes the level of participation of citizens. It is	On the one hand, public services can improve the quality of life, well-being, and human capital of the population, which can, in turn, stimulate their creativity,	Mixed	We expect the sign to be positive since the capacity to introduce innovations is

	related to the efficiency and transparency of public service delivery.	productivity, and entrepreneurship. On the other hand, people who have lower access to public services may be more likely to pursue innovative ideas and projects and seek grants for innovation on blockchain as a way to fund them.		strongly supported by efficient public services.
Number of citable documents per one thousand people (*citdoc*)	It reflects the level of research activity in a country and how it affects the demand for innovation.	A higher number of citable documents implies a more vibrant and dynamic academic environment, where new discoveries and insights are generated and shared. This can foster a culture of innovation and learning and encourage people to apply for grants for innovation on blockchain as a means to advance their research agendas.	Mixed	
Quality-weighted universities (*qualuniv* or *qualuniv*_adj)	It may reflect the potential impact of the high-level educational system on the demand for grants.	The quality of universities can influence the level of innovation and research in various fields, including blockchain technology. Higher-quality universities can attract more talented students and faculty, who can develop new applications and solutions using blockchain. This can create more demand for grants for blockchain adoption, as universities seek to fund their projects and collaborate with other stakeholders in the ecosystem	Mixed	
Government effectiveness (*gov*)	It reflects how the quality and effectiveness of public services and policies can affect blockchain adoption.	Higher government effectiveness implies a more efficient, responsive, and accountable public sector, which can create a favorable institutional environment for innovation and development.	Positive	

Table 112 - Rationale, impact, and expected sign of the independent variables

3.3.3 Methodology

The study estimates the impact of the above independent variables on the number of grants over the available time period 2015-2023 among 33 countries[24] (297 observations in total).

Given the panel nature of the dataset, panel data methods will be used in our study. This entails potential advantages, including: it allows us to control for unobserved heterogeneity that might affect our dependent variable. For instance, some cultural or social aspects of a country might not be observable but influence the interest in blockchain solutions. We can account for these factors using fixed or random effects models. Moreover, panel data enables to study the relationships among variables over time. Since the dataset covers nine years and blockchain technology is still developing, time affects changes in the willingness to invest in blockchain solutions. Furthermore, panel data provides more information, more variability, and more degrees of freedom than other data. This means that panel data can improve the efficiency and precision of our estimates, reduce multicollinearity problems, and allow for more complex and flexible specifications of our model. Panel data can also help us to identify and assess effects that cannot be observed using cross-section or time series data. Therefore, panel data is a powerful and helpful tool for analysis, as it can help to address some of the limitations of other types of data [114, 115, 116].

The dataset is balanced and does not present missing data problems, but the high volatility of the dependent variable determines the need to introduce some corrections.

We recognize that the explanatory variables may have lagged and dynamic effects on the dependent variable, rather than immediate and contemporaneous effects. Thus, we opted to use lagged variables in our model, which reflect the effect of the explanatory variables in the preceding year. For instance, we used GDP from 2013 to 2021, presuming that the economic performance of a country in a certain year affects its ability to attract EU funding for blockchain projects in the subsequent years. Likewise, we used population, population under 25, government effectiveness, and other variables from 2013 to 2021, while ICT, NEET, access to public services, citable documents, and university quality from 2014 to 2022. By using lagged variables, we were able to

[24] The 27 EU countries, plus Israel, Norway, Serbia, Switzerland, Turkey, and the United Kingdom.

incorporate the temporal dynamics of the relationships between the variables and reduce potential endogeneity problems.

We applied a multiple regression model on two different variables — one is the logarithmic transformation of the overall amount of grants per country (in EUR millions) as the dependent variable, and one is the logarithmic transformation of the amount weighted for the population (EUR per one thousand people) as the dependent variable to reduce dependency on the country's size. However, both cases have included the population as an independent variable to contain the size's effect.

The Hausman test confirmed that a fixed-effects panel data model was the most suitable. This test compares the consistency and efficiency of two estimators. The null hypothesis is that both estimators are consistent, and the alternative hypothesis is that only the less efficient one is consistent [117, 118]. For robustness, the Mundlak's approach was used and the Mundlak test was performed. This test consists of using a random effects estimator including both the covariates and the panel-level means of our covariates and testing if the panel-level means are jointly zero [119].

The Bai and Perron test for multiple structural breaks detected changes in the model's parameters over time. The null hypothesis is that there are no breaks, and the alternative hypothesis is that there are breaks. The test confirmed the presence of a break due to COVID-19 that had a lagged effect in years 2021 and 2022 when the impact of restrictions on the economic system occurred. Accordingly, two dummy variables[25] have been introduced to capture the effect [120, 121].

In the final part of the analysis, we performed several robustness checks, including a comparison with the nominal amount of the dependent variables. We also dealt with model uncertainty, both performing a stepwise regression analysis and comparing multiple models to improve robustness and reduce the risk of overfitting and multicollinearity by eliminating insignificant or redundant predictors.

Moreover, we accounted for endogeneity by using lagged explanatory variables [122]. We checked the robustness of our results by using different lag structures and found consistent results across different specifications.

In this respect, access to ICT and the quality of universities might be affected by reverse causality, as countries with higher demand for grants might stimulate the creation of ICT and impact the quality of universities. This could bias the estimated effect on the

[25] 'break21' for the year 2021 and 'break2022' for the year 2022.

demand for grants, as it would capture not only the causal effect of the independent variables but also the feedback effect of blockchain adoption on both.

The quality of universities might be endogenous with respect to the demand for grants for blockchain because there could be a two-way relationship between them. On the one hand, the quality of universities could affect the demand for grants for blockchain, as higher-quality universities might produce more and better research and innovation in blockchain technology, which could increase the demand for grants to support such activities. On the other hand, the demand for grants for blockchain could affect the quality of universities, as higher demand for grants for blockchain might induce more investment and improvement in the quality of universities, especially in the fields related to blockchain technology, such as computer science, engineering, and economics.

The endogeneity for ICT may follow the following mechanism: ICT could affect the demand for grants for blockchain, as higher access to ICT could enable and facilitate more research and innovation in blockchain technology, which could increase the demand for grants to support such activities. Similarly, the demand for grants for blockchain could affect ICT, as higher demand for grants for blockchain might stimulate the creation and improvement of ICT, especially in the areas related to blockchain technology, such as internet connection, electronic devices, and broadband. Therefore, there could also be a feedback loop between ICT and the demand for grants for blockchain, which could create endogeneity problems in estimating their causal effect.

This issue will be addressed using an instrumental variable approach, where the causal effect of respectively “access to ICT” and “quality-weighted universities” on the demand for grants will be isolated, controlling for other factors that might affect both the amount of grants and the selected variable.

3.3.4 Results

First, pairwise correlations have been computed to preliminary evaluate the relationship among variables (Table 13). The results show that EU grants are significantly correlated to population (0.41), access to ICT (0.244), population under 25 years old (-0.137), access to public services inequality (0.150), and quality-weighted universities (0.451). However, the coefficients are relatively low, and the significance is reasonably given mainly by the sample size. Similarly, the EU grants per capita are significantly correlated with GDP per capita (0.341), population (-0.185), access to ICT (0.128), citable documents per one thousand people (0.163), quality-weighted universities total (-0.148) and adjusted (0.321). Overall, these results align with our initial expectations, except for the population under 25 years old. However, it is worth noticing that correlation does not imply causal effects between variables; hence, additional analysis is needed.

After that, we applied the Hausman test to compare the coefficients of the fixed effects and random effects models for panel data. The test rejected the null hypothesis that the difference in coefficients is not systematic. The Mundlak test was also performed. Since the null hypothesis was rejected, it meant that the coefficients were not jointly zero. Thus, the fixed effects model is more appropriate for our analysis. This result is consistent across all the different models estimated.

The general equation for a fixed effects panel data model is the following:

$$y_{it} = \alpha_i + \beta_1 x_{1it} + \beta_2 x_{2it} + \ldots + \beta_k x_{kit} + u_{it}$$

where:

- y_{it} is the dependent variable for subject *i* at time *t*.
- α_i is the fixed effect for the subject i and captures the specific and time-invariant characteristics of each subject.
- $\beta_1, \beta_2, \ldots, \beta_k$ are the coefficients of the independent variables, which measure the average effect of these variables on the dependent variable.
- $x_{1it}, x_{2it}, \ldots, x_{kit}$ are the independent variables for subject *i* at time *t*.
- u_{it} is the error term for subject i at time *t*, which captures the random or unobserved influences on the dependent variable.

We performed the regressions as described.

For the model that considers the logarithmic transformation of the overall amount of EU grants as the dependent variable (Eq. 1), Table 14 reports four outcomes: regression without a structural break, regression with dummy variables for 2021 and 2022, and regression using the dependent variable's nominal value (Eq. 2), both with and without structural breaks.

We followed the same procedure for the model that uses the number of grants divided by the population as the dependent variable (Table 15). In this case, among the independent variables, we introduced the quality-weighted universities adjusted for the country's total population to reduce the size effect instead of the quality-weighted universities total. In our case the dependent variable will be alternatively *grants_pc* or *GRANTS_PC* (Eq. 3 and Eq. 4).

Finally, our models will be as follows:

Eq. 1:

$$grants_{it} = \alpha_i + \beta_1 gdp_{pc_{it}} + \beta_2 pop_{it} + \beta_3 ict_{it} + \beta_4 pop25_{it} + \beta_5 neet_{it} + \beta_6 pubservices_{it} + \beta_7 citdoc_{it} + \beta_8 qualuniv_{it} + \beta_9 gov_{it} + \beta_{10} break21_{it} + \beta_{11} break22_{it} + u_{it}$$

Eq. 2:

$$GRANTS_{it} = \alpha_i + \beta_1 gdp_{pc_{it}} + \beta_2 pop_{it} + \beta_3 ict_{it} + \beta_4 pop25_{it} + \beta_5 neet_{it} + \beta_6 pubservices_{it} + \beta_7 citdoc_{it} + \beta_8 qualuniv_{it} + \beta_9 gov_{it} + \beta_{10} break21_{it} + \beta_{11} break22_{it} + u_{it}$$

Eq. 3:

$$grants\_pc_{it} = \alpha_i + \beta_1 gdp_{pc_{it}} + \beta_2 pop_{it} + \beta_3 ict_{it} + \beta_4 pop25_{it} + \beta_5 neet_{it} + \beta_6 pubservices_{it} + \beta_7 citdoc_{it} + \beta_8 qualuniv_{adj_{it}} + \beta_9 gov_{it} + \beta_{10} break21_{it} + \beta_{11} break22_{it} + u_{it}$$

Eq. 4:

$$GRANTS\_PC_{it} = \alpha_i + \beta_1 gdp_{pc_{it}} + \beta_2 pop_{it} + \beta_3 ict_{it} + \beta_4 pop25_{it} + \beta_5 neet_{it} + \beta_6 pubservices_{it} + \beta_7 citdoc_{it} + \beta_8 qualuniv_{adj_{it}} + \beta_9 gov_{it} + \beta_{10} break21_{it} + \beta_{11} break22_{it} + u_{it}$$

Table 13 - Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) grants	1.000										
(2) grants_pc	0.972***	1.000									
	(0.000)										
(3) gdp_pc	0.198***	0.251***	1.000								
	(0.001)	(0.000)									
(4) pop	0.223***	0.037	-0.100*	1.000							
	(0.000)	(0.521)	(0.084)								
(5) ict	0.407***	0.420***	0.495***	0.010	1.000						
	(0.000)	(0.000)	(0.000)	(0.860)							
(6) pop25	0.014	-0.006	0.198***	0.165***	-0.024	1.000					
	(0.813)	(0.915)	(0.001)	(0.004)	(0.680)						
(7) neet	-0.146**	-0.213***	-0.518***	0.305***	-0.616***	0.240***	1.000				
	(0.012)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
(8) pubservices	0.151***	0.190***	0.420***	-0.183***	0.400***	-0.311***	-0.620***	1.000			
	(0.009)	(0.001)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)				
(9) citdoc	0.207***	0.268***	0.747***	-0.261***	0.613***	0.052	-0.654***	0.507***	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.374)	(0.000)	(0.000)			
(10) qualuniv	0.262***	0.109*	0.103*	0.835***	0.313***	0.018	-0.020	0.049	0.017	1.000	
	(0.000)	(0.061)	(0.077)	(0.000)	(0.000)	(0.761)	(0.729)	(0.396)	(0.768)		
(11) qualuniv_adj	0.145**	0.244***	0.491***	-0.317***	0.522***	0.057	-0.454***	0.418***	0.584***	-0.026	1.000
	(0.013)	(0.000)	(0.000)	(0.000)	(0.000)	(0.330)	(0.000)	(0.000)	(0.000)	(0.650)	
(12) gov	0.183***	0.217***	0.769***	-0.106*	0.573***	0.156***	-0.643***	0.553***	0.737***	0.194***	0.608***
	(0.001)	(0.000)	(0.000)	(0.067)	(0.000)	(0.007)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)

VARIABLES	(1) grants	(2) grants	(3) GRANTS	(4) GRANTS
gdp_pc	-0.0721	-0.0913	-0.102	-0.137*
	(0.0672)	(0.0642)	(0.0788)	(0.0753)
pop	0.192	0.291	-1.074	-0.911
	(0.645)	(0.610)	(0.756)	(0.716)
ict	0.242***	0.246***	0.105	0.0971
	(0.0779)	(0.0740)	(0.0913)	(0.0869)
pop25	-2.544***	-3.080***	-0.623	-1.303
	(0.859)	(0.819)	(1.007)	(0.961)
neet	-0.348	-0.690***	-0.378	-0.831***
	(0.226)	(0.226)	(0.265)	(0.265)
pubservices	-0.180	0.234	2.736	3.672
	(2.638)	(2.512)	(3.094)	(2.948)
citdoc	-4.369***	-4.746***	-3.414*	-3.455*
	(1.618)	(1.549)	(1.898)	(1.819)
qualuniv	-0.0472	-0.0327	0.160***	0.177***
	(0.0408)	(0.0386)	(0.0478)	(0.0453)
gov	7.152**	7.392***	3.129	2.964
	(2.787)	(2.648)	(3.268)	(3.109)
break21		-4.944***		-5.434***
		(0.872)		(1.024)
break22		-1.985**		-3.590***
		(0.913)		(1.072)
Constant	52.59	68.45**	20.13	40.64
	(36.28)	(34.44)	(42.55)	(40.43)
Observations	297	297	297	297
R-squared	0.211	0.301	0.115	0.214
Number of countries	33	33	33	33
Fixed effects	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14 – Outcome (1) – Total EU grants

VARIABLES	(5) grants_pc	(6) grants_pc	(7) GRANTS_PC	(8) GRANTS_PC
gdp_pc	-0.0593	-0.0787	32.15*	26.81
	(0.0607)	(0.0576)	(18.07)	(17.86)
pop	-0.307	-0.111	-10.82	33.30
	(0.528)	(0.498)	(157.2)	(154.4)
ict	0.192***	0.199***	4.761	4.439
	(0.0696)	(0.0657)	(20.73)	(20.39)
pop25	-2.360***	-2.802***	-204.1	-295.1
	(0.820)	(0.775)	(244.2)	(240.2)
neet	-0.248	-0.583***	66.80	-4.441
	(0.197)	(0.197)	(58.75)	(61.21)
pubservices	-0.0410	0.340	1,136	1,266*
	(2.371)	(2.243)	(705.9)	(695.4)
citdoc	-3.607**	-3.912***	-363.8	-371.4
	(1.441)	(1.371)	(429.0)	(425.3)
qualuniv_adj	-0.0516	0.00267	297.9***	309.1***
	(0.370)	(0.348)	(110.3)	(107.9)
gov	6.588***	6.683***	-157.7	-196.6
	(2.475)	(2.337)	(736.8)	(724.7)
break21		-4.652***		-849.5***
		(0.777)		(240.8)
break22		-1.811**		-508.6**
		(0.814)		(252.4)
Constant	55.06	67.20**	563.8	3,117
	(34.07)	(32.08)	(10,143)	(9,948)
Observations	297	297	297	297
R-squared	0.196	0.297	0.066	0.113
Number of countries	33	33	33	33
Fixed effects	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 15 – Outcome (2) – EU grants per capita

Based on the results, we can draw the following conclusions:

- The graphical representation of the data reveals an evident structural break due to the COVID-19 pandemic outbreak. The coefficients are negative and statistically significant, and the impact is substantial. The outcome is consistent in both the model that uses the overall amount and the model with the per capita amount, and it is also corroborated by using logarithmic transformations.

- Regarding the individual variables, GDP per capita has a negative coefficient. However, it is not statistically significant, possibly because the effect on the dependent variable of a change in GDP per capita is hard to be captured since variations are less pronounced in such a short period. The results are consistent in the case of the nominal overall amount. The sign of the coefficient can be explained as follows: countries with higher income have a lower need to resort to grant resources for innovative investments. On the contrary, the coefficient is positive in the per capita model with the nominal values. Still, the variable is not statistically significant. However, the heterogeneity of the sample reduces the ability to capture the effect of this variable. This ambiguity calls for further investigation.
- According to our preliminary hypotheses, the total population has coefficients that move in opposite directions. Raw data showed higher amounts for large countries in the model that studies the overall amount. The opposite happens in the model with grants per capita. The coefficients show the expected sign in the log-linear model. It is noteworthy that the logarithm of the variable appears more reliable in capturing the effects of independent variables than the nominal amount, where coefficients show opposite signs to what we would expect. The population has poorly significant coefficients in all cases, indicating a limited impact.
- In the case of access to ICT, results are in accordance with expectations. The coefficients show a positive and significant effect. This confirms initial premises on the need for adequate digital infrastructures to direct innovation.
- The percentage of the population under 25 years old has a negative effect, and its coefficient is statistically significant. Logic would suggest that younger populations are more prone to innovation, so results are unexpected. This outcome may be related to the fact that older people consider innovation riskier and tend to resort to gift resources rather than invest with their capital.
- The percentage of neet has a negative and statistically significant effect. In line with expectations, countries where the young population is employed have greater incentives to innovate.

- Access to public services equality positively affects variables. It indicates ease in adopting disruptive and decentralized technological solutions like blockchain. However, the significance of the coefficient is low, suggesting that the model generally does not capture its effect on the willingness of businesses and citizens to seek innovations.
- A rather unexpected result relates to the number of citable documents per inhabitant, which aims to measure scientific research's quality and proliferation. Indeed, its negative and statistically significant coefficient calls for further investigation. For instance, it would be worth looking more closely at the sectors most exploited by research to understand if it is well addressed. In addition, excess in scientific production could represent a market saturation at an inability to select studies more oriented toward practical applications. Of course, those are just speculative arguments far from being comprehensive, and, as mentioned, they would need further rigorous scrutiny.
- Quality of universities has a positive impact. The result is consistent in both models, despite having used a weighting in the case of the per capita model. However, the coefficient is not significant in the log-linear models, suggesting that a form of endogeneity may occur – on the contrary, it gains significance when we use the nominal values of the dependent variables. In practice, the quality of universities fosters research and the ability to innovate, and this ability, in turn, improves the quality of universities themselves. Therefore, the model fails to capture the effect on the dependent variable. In addition, the variability in the quality of universities, in a limited time range, could be highly reduced.
- Finally, government effectiveness has a positive coefficient and is statistically significant. The coefficient, instead, is not statistically significant in the case of nominal values. The positive sign confirms what was already said: a more efficient bureaucratic apparatus guarantees a more productive fabric prone to innovate and experiment with new solutions.

The following tables report the results of the stepwise method for all models, which essentially corroborate the findings obtained so far (Tables 16 and 17), and two endogeneity tests using an instrumental variable model (Table 18 for the quality of universities and Table 19 for access to ICT). In this case, the lagged variable itself is used as an instrument under the assumption that it affects the current value of the explanatory variable but not the present value of the outcome variable or the error term.

VARIABLES	(2) grants	(9) grants	(6) grants_pc	(10) grants_pc
gdp_pc	-0.0913		-0.0787	
	(0.0642)		(0.0576)	
pop	0.291		-0.111	
	(0.610)		(0.498)	
ict	0.246***	0.240***	0.199***	0.198***
	(0.0740)	(0.0731)	(0.0657)	(0.0652)
pop25	-3.080***	-3.298***	-2.802***	-2.879***
	(0.819)	(0.769)	(0.775)	(0.685)
neet	-0.690***	-0.603***	-0.583***	-0.551***
	(0.226)	(0.214)	(0.197)	(0.191)
pubservices	0.234		0.340	
	(2.512)		(2.243)	
citdoc	-4.746***	-5.617***	-3.912***	-4.518***
	(1.549)	(1.399)	(1.371)	(1.247)
qualuniv	-0.0327			
	(0.0386)			
gov	7.392***	7.859***	6.683***	7.079***
	(2.648)	(2.479)	(2.337)	(2.210)
break21	-4.944***	-4.931***	-4.652***	-4.610***
	(0.872)	(0.865)	(0.777)	(0.771)
break22	-1.985**	-1.836**	-1.811**	-1.650**
	(0.913)	(0.892)	(0.814)	(0.795)
qualuniv_adj			0.00267	
			(0.348)	
Constant	68.45**	75.47***	67.20**	65.17***
	(34.44)	(27.63)	(32.08)	(24.63)
Observations	297	297	297	297
R-squared	0.301	0.294	0.297	0.291
Number of countries	33	33	33	33
Fixed effects	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 16 – Outcome (3) – Robustness analysis, stepwise approach

VARIABLES	(4) GRANTS	(11) GRANTS	(8) GRANTS_PC	(12) GRANTS_PC
gdp_pc	-0.137*	-0.179**	26.81	
	(0.0753)	(0.0700)	(17.86)	
pop	-0.911		33.30	
	(0.716)		(154.4)	
ict	0.0971		4.439	
	(0.0869)		(20.39)	
pop25	-1.303		-295.1	-293.4**
	(0.961)		(240.2)	(148.0)
neet	-0.831***	-1.026***	-4.441	
	(0.265)	(0.227)	(61.21)	
pubservices	3.672	4.900*	1,266*	1,330**
	(2.948)	(2.661)	(695.4)	(649.4)
citdoc	-3.455*		-371.4	
	(1.819)		(425.3)	
qualuniv	0.177***	0.157***		
	(0.0453)	(0.0389)		
gov	2.964		-196.6	
	(3.109)		(724.7)	
break21	-5.434***	-5.173***	-849.5***	-825.3***
	(1.024)	(1.015)	(240.8)	(228.1)
break22	-3.590***	-3.801***	-508.6**	-533.1**
	(1.072)	(1.036)	(252.4)	(234.7)
qualuniv_adj			309.1***	274.0***
			(107.9)	(103.6)
Constant	40.64	-0.926	3,117	3,344
	(40.43)	(10.87)	(9,948)	(4,136)
Observations	297	297	297	297
R-squared	0.214	0.192	0.113	0.103
Number of countries	33	33	33	33
Fixed effects	Yes	Yes	Yes	Yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 17 – Outcome (4) – Robustness analysis, stepwise approach

VARIABLES	(13) grants	(14) grants_pc	(15) GRANTS	(16) GRANTS_PC
qualuniv	-0.0330**		-0.00445	
	(0.0165)		(0.0246)	
qualuniv_adj		0.361		403.2***
		(0.292)		(102.9)
gdp_pc	-0.0160	0.00498	-0.000556	42.48***
	(0.0326)	(0.0269)	(0.0479)	(9.520)
pop	0.145***	0.0198	0.160**	-5.048
	(0.0494)	(0.0202)	(0.0747)	(7.263)
ict	0.271***	0.195***	0.193**	-1.274
	(0.0704)	(0.0629)	(0.0912)	(20.78)
pop25	-0.0786	-0.00672	-0.261	-34.73
	(0.142)	(0.113)	(0.215)	(40.42)
neet	-0.186	-0.122	-0.176	2.607
	(0.151)	(0.127)	(0.211)	(43.62)
pubservices	-0.260	-0.119	2.565	-118.4
	(1.298)	(1.087)	(1.855)	(378.7)
citdoc	0.134	0.0357	-1.250	-454.6**
	(0.737)	(0.616)	(1.074)	(217.1)
gov	0.195	-1.464	0.287	-1,022**
	(1.472)	(1.240)	(2.062)	(427.2)
break21	-3.845***	-3.669***	-4.277***	-801.3***
	(0.875)	(0.786)	(1.071)	(248.3)
break22	-1.207	-1.149	-2.343**	-428.6*
	(0.885)	(0.799)	(1.088)	(253.0)
Constant	-6.315	-0.279	-11.11	4,024
	(9.357)	(8.192)	(13.16)	(2,817)
Observations	264	264	264	264
Number of countries	33	33	33	33

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 18 – Outcome (5) – Robustness analysis, instrumented variable ‘quality-weighted universities’

VARIABLES	(17) grants	(18) grants_pc	(19) GRANTS	(20) GRANTS_PC
ict	0.401***	0.289***	0.422***	16.48
	(0.0962)	(0.0835)	(0.131)	(28.45)
gdp_pc	-0.0168	0.00440	-0.000863	42.07***
	(0.0325)	(0.0269)	(0.0481)	(9.620)
pop	0.140***	0.00922	0.0790	-8.291
	(0.0481)	(0.0206)	(0.0724)	(7.532)
pop25	-0.0657	0.00558	-0.166	-31.64
	(0.142)	(0.113)	(0.215)	(41.03)
neet	-0.0986	-0.0607	0.0411	14.59
	(0.155)	(0.132)	(0.221)	(45.89)
pubservices	-0.0310	0.0515	3.194*	-64.48
	(1.300)	(1.091)	(1.876)	(383.8)
citdoc	-0.293	-0.209	-2.243**	-476.8**
	(0.766)	(0.635)	(1.138)	(227.2)
qualuniv	-0.0356**		0.0165	
	(0.0163)		(0.0240)	
gov	0.203	-1.370	0.0208	-906.7**
	(1.471)	(1.225)	(2.077)	(424.6)
break21	-4.194***	-3.886***	-4.851***	-815.5***
	(0.899)	(0.801)	(1.107)	(251.6)
break22	-1.463	-1.290	-2.729**	-420.7*
	(0.901)	(0.806)	(1.111)	(253.3)
qualuniv_adj		0.231		313.4***
		(0.248)		(85.20)
Constant	-18.36*	-9.011	-34.29**	2,142
	(11.11)	(9.571)	(16.16)	(3,382)
Observations	264	264	264	264
Number of country	33	33	33	33

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 19 – Outcome (6) – Robustness analysis, instrumented variable ‘access to ICT’

3.4 Implications and Conclusions

This section aimed to explore the factors affecting investment decisions in blockchain solutions in the EU and associated countries, using a panel data model with data from 2015 to 2023.

The findings have several implications which are relevant for both theory and practice. First, they contribute to the literature on blockchain innovation by providing empirical evidence on the factors that influence investment decisions in this field across countries and regions. Second, they provide insights for policymakers who want to foster blockchain innovation by identifying the key drivers and barriers that affect this process. Third, they suggest areas for future research that can further advance our understanding of blockchain innovation and its outcomes.

The results suggest that the adoption and diffusion of this technology (as measured by EU funding) depend on various demographic, social, organizational, educational, institutional, political, economic, and technological factors.

However, in interpreting these results, it is worth noticing that the stage of development is still premature, and the level of investments is relatively low and heterogeneous. No clear pattern or trend can be observed except for increasing attention to this technology. This suggests there is still much uncertainty and experimentation in this field.

Therefore, the willingness to innovate depends on the effort of the research and development sector. This implies that countries that invest more in scientific and technological research are more likely to explore and adopt innovative solutions based on blockchain. However, results are ambiguous since the quantity of scientific research could negatively affect the demand for grants. It might indicate a higher level of competition and saturation. As mentioned, there is a need for further analysis because this variable is not sector specific.

The quality of the existing technological infrastructure is crucial. Indeed, we found that access to ICT has a positive and significant effect on the number of investments in blockchain technology. Arguably, countries with a more efficient digital infrastructure are more prepared to implement and use blockchain-based solutions.

Some demographic and social factors insights have been discussed, primarily on the population's capacity to research alternative technologies. The finding somewhat contradicts the assumption that younger generations are more bullish on cryptocurrencies and other blockchain-based applications. Several possible explanations can be offered for this result. One of them is that younger people may perceive blockchain as too risky or complex and prefer to invest in more familiar or established assets. Another is that younger people may have less disposable income or access to financial resources to invest in blockchain. A third explanation might be that younger people may have different preferences or values than older generations and may need to see the benefits or relevance of blockchain for their needs or goals. Whatever the reason, this finding suggests a need for more education and awareness-raising on blockchain technology and its potential among the youngest population, as well as more incentives and support for their participation and involvement in blockchain innovation.

On the contrary, the economy's rigidity and lack of flexibility could slow down the process. A rigid and inflexible economy may hinder the development and diffusion of blockchain solutions, as it may create barriers to entry, limit competition, and discourage experimentation and risk-taking.

Finally, the policymaker has a crucial role in fostering blockchain adoption. We found that regulatory quality, government effectiveness, and access to public services are essential in supporting innovation. Put differently, countries relying on a more transparent and effective regulatory framework are more conducive to innovation. Policymakers can support blockchain experimentation by providing legal certainty, reducing administrative burdens, facilitating cross-border cooperation, and promoting public-private partnerships. Also, they can ensure that regulations are targeted and proportionate to protect consumers and investors without stifling innovation. Policymakers can also invest in research and development, education and training, and awareness-raising on blockchain technology and its applications. They can also provide resources and policy initiatives to encourage innovation and risk-taking by entrepreneurs and researchers. Policymakers must foster collaboration and coordination among distinct levels of government and with other countries and regions on blockchain policy issues.

Admittedly, the study has some limitations. For instance, there might be omitted variables not captured by the model and reverse causality between some variables. Future research could investigate the effects of different indicators on the blockchain.

Also, the panel data model used in this study assumes that the effects of the explanatory variables are constant across countries and time. However, this may be unrealistic as different countries have different institutional settings and policy frameworks affecting innovation performance. Therefore, future research could use a more flexible model for country-specific or time-varying effects.

The data used in this study covers only a short period (five years) and may not capture the long-term effects of funding for innovation in blockchain. Therefore, future research could extend the data to a longer period and examine the dynamic relationships between funding and innovation outcomes.

Furthermore, the research focuses only on one type of funding source (public EU grants) and does not account for other sources of financing, such as private investments, crowdfunding, or loans. Therefore, future research could collect data on different funding sources and compare their effects on innovation in blockchain.

Finally, the data has a low level of granularity, as it aggregates funding information at the country level and needs to account for variations within countries or across distinct types of projects - or at the firm level. A higher level of granularity would allow for a more accurate and nuanced analysis of the factors.

In conclusion, the results provide valuable insights into the factors influencing blockchain innovation and adoption. This is a fascinating and emerging field of research that has many implications for theory and practice. There is a high expectation for future development and advancement of this technology and its applications across various sectors and contexts.

CONCLUSION

Blockchain technology is a novel and disruptive innovation that can transform various fields of society and the economy. It is a transparent and decentralized system of recording transactions that uses a distributed ledger secured by cryptography and governed by a consensus mechanism [1]. It can store and transfer any digital information without intermediaries or central authorities.

The first and most prominent application of blockchain technology is Bitcoin, a cryptocurrency that enables peer-to-peer transfer of value over the internet [2]. Bitcoin sparked the interest of researchers and the financial market as it demonstrated the feasibility and advantages of using blockchain technology for digital currencies.

However, blockchain technology is not limited to cryptocurrencies. It can also enable various other applications that require trust, transparency, security, and efficiency in different fields, such as finance, healthcare, supply chain, Internet of Things (IoT), media, and government [6]. It can also enhance the accountability and traceability of data and transactions, ensuring their integrity and authenticity. Moreover, it can foster innovation and stakeholder collaboration by creating new business models and opportunities.

Blockchain technology is a complex and multidisciplinary phenomenon that poses significant challenges and opportunities for research and practice. It requires a comprehensive and systematic analysis of its technical, economic, social, legal, ethical, and political implications. Therefore, various research methodologies have been applied to study blockchain technology and its applications from different perspectives and disciplines [7].

Chapter 1 reviewed the primary research methodologies used for blockchain technology, such as bibliometric analysis, systematic literature review, systematic mapping study, and case study. Advantages and disadvantages have been compared, and suggestions have been proposed on how they can be used individually or in combination to address several aspects or objectives of blockchain research.

Bibliometric analysis is a quantitative method that can provide an overview of blockchain research's state of the art and evolution over time by measuring publications' scientific output and impact on a given topic [47]. It can identify the main authors, journals, institutions, countries, keywords, citations, and trends in the literature. It can also reveal the research gaps and opportunities for future studies.

Systematic literature reviews compare and contrast different approaches, theories, models, frameworks, findings, and implications of previous studies, identify the strengths and weaknesses of the literature, and suggest directions for future research [35]. They can provide a critical and comprehensive assessment of blockchain research and its contribution to knowledge.

A third research methodology used for blockchain technology is the systematic mapping study. This method classifies and categorizes the literature on a given topic according to specific criteria or dimensions [11]. It can provide an overview of the literature's scope, coverage, diversity, and distribution. It can also identify the research themes, questions, methods, results, and challenges in the literature, providing a structured and organized representation of blockchain research and its characteristics.

A fourth research methodology used for blockchain technology is the case study. A case study is a method that investigates a specific phenomenon or context in depth using multiple sources of evidence [22]. It can provide rich and detailed descriptions and explanations of real-world situations or problems involving blockchain technology and its applications. It can also generate insights and lessons learned from practical experiences and best practices. A case study can provide an empirical and contextualized understanding of blockchain research and its outcomes.

These research methodologies are not mutually exclusive or exhaustive but complementary and interrelated. They can be used individually or in combination to address several aspects or objectives of blockchain research. They can also be applied to specific domains or sectors where blockchain technology has been implemented or has potential applications.

One of the main fields where blockchain technology has been implemented or has potential applications is the public sector. The public sector faces challenges such as inefficiency, corruption, bureaucracy, fraud, lack of transparency, accountability, and trust. Blockchain technology can offer many benefits for the public sector, such as improving efficiency, reducing costs, enhancing trust, and fostering innovation. However, blockchain technology poses challenges and limitations such as scalability, interoperability, regulation, education, and adoption [51].

Two case studies of blockchain applications for the public sector have been presented. These case studies demonstrate how blockchain can enhance efficiency, transparency, security, and trust in public services and administration.

Therefore, the policymaker needs to carefully assess the opportunities and risks of blockchain technology for their specific contexts and objectives. It must also collaborate with other stakeholders, such as researchers, developers, businesses, and civil society, to create an enabling environment for blockchain innovation. Some implications and recommendations for the policymaker are:

- Lead the process in cooperation with stakeholders and establish a smart social contract based on blockchain.
- Implement blockchain gradually and adaptively, involving consultation and education of the public.
- Adopt the latest and most suitable blockchain solutions for their contexts and anticipate potential problems.
- Ensure the availability and accessibility of digital infrastructures to support blockchain adoption and reduce the digital divide.
- Conduct a technical evaluation of blockchain types and features and choose the most appropriate ones for their goals.
- Establish a legal or regulatory framework for blockchain that defines rights and obligations, facilitates interoperability and trust, and protects privacy and security.
- Encourage citizens' development of blockchain solutions through monetary incentives or private initiatives.

Chapter 3 examines the role of European institutions in promoting and regulating blockchain technology and its applications, describes the main initiatives and funding programs of the European Union, and offers additional data on the distribution by year, sector, and country. A panel data econometric model has been proposed to assess the main drivers that facilitate blockchain implementation and the role of the policymaker in addressing potential limits. The model uses data from thirty-three countries for nine years.

The analysis proposes some implications and findings for theory and practice and suggests future research areas. The study identifies various demographic, social, organizational, educational, institutional, political, economic, and technological factors influencing blockchain adoption and diffusion across countries and regions. It also highlights the role of policymakers in fostering blockchain innovation by providing legal certainty, reducing administrative burdens, facilitating cross-border cooperation, promoting public-private partnerships, investing in research and development, education and training, and awareness-raising. The model emphasizes that the implementation strategy should consider each area and sector's local needs and characteristics and encourage citizen participation and involvement in blockchain innovation.

However, the study has some limitations and suggests future research directions to address research on blockchain adoption and the policymaker’s role, such as:

- Including more variables and addressing reverse causality issues.
- Using a more flexible model for country-specific or time-varying effects.
- Extending the data to a longer period and examining the dynamic relationships.
- Collecting data on different funding sources and comparing their effects.
- Increasing the level of granularity of the data and accounting for variations within or across investments.

In conclusion, blockchain technology is a fascinating and emerging research field with several implications for theory and practice. There is a high expectation for future development and advancement of this technology and its applications across various sectors and contexts. Blockchain technology can facilitate interactions and transactions among multiple parties without intermediaries or central authorities, reducing costs, risks, and delays.

Scientific research is essential for advancing our understanding of blockchain technology and its outcomes, providing empirical evidence, theoretical frameworks, analytical tools, and practical solutions for blockchain-related issues and problems. It can also generate insights from real-world experiences and best practices. At the same time, it can help the policymaker provide a legal, technical, and economic environment that can foster innovation, research, and investments in this field.

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