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ΑΙΓΑΙΟΥ

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## **Ανασκόπηση εφαρμογών και υποδομών για την τεχνολογία blockchain**

**(The blockchain technology: a review of  
applications and infrastructure)**

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## ΠΕΡΙΛΗΨΗ

Η τεχνολογία Blockchain (BCT: blockchain technology) αναδεικνύεται ως ένα ισχυρό εργαλείο με εφαρμογές που εκτείνονται σε πολλούς τομείς, φέρνοντας την επανάσταση στον τρόπο διαχείρισης δεδομένων και στην εκτέλεση συναλλαγών. Αυτό το άρθρο παρουσιάζει μία λεπτομερή ανάλυση των δύο ρόλων της τεχνολογίας blockchain: τις εφαρμογές της σε διάφορους τομείς και την βασική υποδομή που καθιστά αυτές τις εφαρμογές δυνατές. Εξετάζοντας διάφορες λύσεις blockchain, από δημόσια (public) και ιδιωτικά (private) έως υβριδικά (hybrid) συστήματα, μαζί με μηχανισμούς συναίνεσης (consensus mechanisms), την τεχνολογική ετοιμότητα (technology readiness) και μοντέλα διακυβέρνησης, αυτή η μελέτη στοχεύει στην παροχή μιας περιεκτικής επισκόπησης της τρέχουσας κατάστασης και των μελλοντικών δυνατοτήτων της τεχνολογίας blockchain. Επισημαίνοντας τη σημασία της τεχνολογίας blockchain πέρα από τα κρυπτονομίσματα, αυτό το άρθρο αξιολογεί τον αντίκτυπο της στην ενίσχυση της διαφάνειας, της ασφάλειας και της αποτελεσματικότητας σε διάφορους κλάδους και την σύνδεσή της με τους Στόχους Βιώσιμη Ανάπτυξης (SDGs). Αυτή η ανάλυση επιδιώκει να εμπλουτίσει την κατανόηση και να προωθήσει την καινοτομία στις εφαρμογές και τις υποδομές της τεχνολογίας blockchain, προετοιμάζοντας το έδαφος για την ευρύτερη υιοθέτηση και προαγωγή της.

## ABSTRACT

Blockchain technology (BCT) is emerging as a powerful tool with applications stretching across multiple sectors, revolutionizing how data is managed and transactions are executed. This paper presents an in-depth analysis of blockchain's dual role: its applications across different domains and the foundational infrastructure enabling these applications. By examining various blockchain solutions, from public and private to hybrid systems, alongside consensus mechanisms, technological readiness and governance models, this study aims to provide a comprehensive overview of the current state and future potential of blockchain technology. Highlighting the significance of blockchain beyond cryptocurrencies, the paper assesses its impact on enhancing transparency, security and efficiency across industries and its alignment with the Sustainable Development Goals (SDGs). This analysis seeks to enrich understanding and foster innovation in blockchain applications and infrastructures, paving the way for its broader adoption and advancement.

## 1. INTRODUCTION

Blockchain technology began as the foundation for digital currencies (Bitcoin being the most famous one), but its use has grown far beyond just powering cryptocurrencies. Now, it's recognized for its potential to bring significant improvements across various industries by altering how digital information is managed and transactions are executed online. This paper dives into the diverse applications of blockchain and the infrastructure enabling them. It explores how blockchain's secure, decentralized system not only introduces transparency and reliability to online transactions but also supports innovations in areas like finance, healthcare and even government processes.

The analysis presented aims to provide a thorough overview of how blockchain technology is currently being used, the challenges it faces and its future prospects for broader societal and economic benefits. Additionally, the paper examines blockchain's role in the pursuit of global sustainability, focusing on its alignment with the Sustainable Development Goals established by the United Nations.

This document intends to clarify the wide-reaching applications of blockchain technology and highlight the essential infrastructure that supports its growth and adoption. By providing a clear overview of blockchain technology's practical uses and potential, the paper encourages ongoing research and innovation in this rapidly evolving area.

## 2. Background

### 2.1. BCT Types (Private, Public, Hybrid)

Blockchain technology, with its revolutionary impact across various sectors, presents a diverse array of types, each catering to specific needs and functionalities. Before we delve deeper into the intricacies of BCTs in later chapters, it is crucial to understand the foundational classification of blockchain types - public, private and hybrid - which form the backbone of this technology's adaptability and application.

Public blockchains epitomize the essence of decentralization, offering unrestricted access and fostering an environment of transparency and security. Their open-source nature has been pivotal in the development of digital currencies, transforming financial transactions and data integrity globally. However, the scalability and environmental impacts of public blockchains, especially those employing energy-intensive consensus mechanisms like Proof of Work (PoW), pose significant challenges, drawing attention to the need for more sustainable solutions.

Private blockchains, in contrast, offer a more controlled environment. Their restricted access makes them suitable for corporate applications where privacy and security of sensitive data are paramount. Yet, this centralization deviates from the decentralization principle, a core tenet of blockchain technology, leading to potential vulnerabilities in terms of security and resistance to data manipulation.

Hybrid blockchains merge the benefits of both public and private types, providing a balanced approach for organizations requiring both confidentiality and transparency. They allow certain information to be kept private while making other parts of the public ledger, catering to specific business requirements.

The selection of a specific blockchain type is critical, depending on the BCT's needs for decentralization, transparency and privacy. Understanding these types lays the groundwork for a comprehensive analysis of blockchain technology's diverse applications and infrastructures and their transformative potential across various industries.

In the research and collection of the data that was used for this paper, particular attention was given to ensure the inclusion of blockchain types that extend beyond mere cryptocurrency functionalities. Explicitly, blockchain types that were solely cryptocurrencies without additional functionalities were deliberately omitted from this research. This strategic selection criterion was pivotal in ensuring that the focus of the paper was on blockchains that offer a wider array of applications and services, aiming to present a broad view of blockchain technology's potential beyond its financial applications.

In this chapter, we set the stage for a detailed exploration of these blockchain types, providing a context that enriches our understanding of their applications, as highlighted in the data of this paper. This introduction serves as a foundation for the very detailed and in-depth analysis that follows, where we will delve into each type's specific attributes, benefits and challenges.

### 2.2. Consensus mechanism background

#### **Introduction to Consensus Mechanisms**

Something that will be explored later in this paper in much more depth, particularly in the comprehensive analysis, are consensus mechanisms, which are fundamental to the operation of blockchain technology. They serve as a critical method for achieving agreement among distributed nodes concerning the blockchain's state. This function is indispensable for maintaining the integrity and reliability of a decentralized network. As we will see, ensuring all participants have a consistent view of the ledger is crucial for its immutability and trustworthiness. These mechanisms not only facilitate agreement but also reinforce the security and coherence of the blockchain, a theme that will be recurrent in our later discussions [6][7].

#### **Evolution and Types of Consensus Mechanisms**

The development of consensus mechanisms has been a response to the changing needs of network environments. Initially designed for local networks, the advent of blockchain technologies necessitated scalable and robust consensus protocols for the large, open Internet. This led to the creation of protocols like Redbelly and Dumbo, which demonstrate scalability in large-scale networks and efficiency in asynchronous network conditions [7][8].

#### **Detailed Examination of Consensus Mechanisms**

- **Proof of Work (PoW)**: This mechanism, exemplified by Bitcoin, relies on miners competing to solve cryptographic problems to validate transactions and create new blocks. While secure, PoW is energy-intensive and less efficient at scale, as each block's creation requires significant computational power [6][7].
- **Proof of Stake (PoS)**: Used by well-known blockchains like Ethereum, PoS offers a more energy-efficient mechanism than PoW. Nodes validate transactions based on their stake in the network, making it more scalable and environmentally friendly. However, it may raise concerns about network security and miner motivation [6][7].
- **Practical Byzantine Fault Tolerance (PBFT)**: PBFT addresses issues in asynchronous systems by enabling a system to function even with a fraction of Byzantine (malicious) nodes. This mechanism is optimized for distributed computing, emphasizing low overhead and high fault tolerance [6][7].
- **RAFT**: Focused on non-Byzantine failures, RAFT provides strong consistency and is designed for systems that can tolerate non-malicious node failures. It is particularly noted for its network transmission efficiency and simplicity, as it does not account for Byzantine nodes [6][7].

#### **Application in Various Blockchain Technologies**

- **Universa**: Employs PoS, aligning with the need for energy efficiency and scalability. This approach is reflective of the shift towards mechanisms that balance environmental concerns with network performance [6][7][14].
- **DOVU**: Introduces "Proof of Carbon", showcasing the adaptability of consensus mechanisms to niche application areas like ecological sustainability [6][7][16].

#### **Role of Consensus Mechanisms in Network Security**

Consensus mechanisms are pivotal in enhancing network security, especially in decentralized environments where nodes with diverse interests must reach a unified agreement. They validate changes to the ledger according to agreed-upon network rules, thus preventing fraudulent activities and double-spending [6][7].

#### **Conclusion**

In summary, the diverse consensus mechanisms employed in blockchain technologies underline the adaptability of blockchain to meet different sectoral needs. The developments in these mechanisms point to an ongoing evolution aimed at creating more efficient, secure and scalable blockchain networks. The varied applications in the dataset of this paper illustrate the mechanisms' critical role in defining network functionality and scope [6][7].

### **2.3. Types of solutions**

In the evolving landscape of blockchain technology, understanding the distinction between applications and infrastructure, as well as their individual functionalities, is crucial. This paper synthesizes information from several authoritative sources to provide a comprehensive overview of blockchain applications and infrastructure, designed for readers unfamiliar with these concepts and introduces the dataset of multiple blockchain solutions within the realm of blockchain technologies (BCTs). Emphasizing this binary classification is critical, as it serves as the foundation for the paper's analytical framework, facilitating a detailed exploration of how blockchain technology is revolutionizing both operational infrastructures and sector-specific applications.

### **Introduction to Blockchain Technologies (BCTs)**

The dataset presented in this paper encompasses a wide range of blockchain technologies (BCTs), highlighting the diversity and innovation within the field. Within this dataset, BCTs are categorized into two primary types of blockchain solutions: applications and infrastructure. This categorization is essential for understanding the wide scope of blockchain's impact across various sectors and its potential for future developments.

### **Understanding Blockchain Infrastructure**

Blockchain infrastructure refers to the foundational technology layers and services that enable blockchain applications to operate. It includes the hardware, software, protocols and networks, the essential components that form the backbone of any blockchain system. Infrastructure is vital for the security and functionality of blockchain networks, offering the computational resources, secure transaction protocols and consensus mechanisms (like Proof of Work or Proof of Stake) necessary for the blockchain's operation. [13]

### **Grasping Blockchain Applications**

Contrastingly, blockchain applications represent the user-oriented services and solutions that utilize the underlying infrastructure to deliver specific functionalities. These applications harness the decentralized, secure and transparent nature of blockchain technology to offer specific functionalities to end-users. Applications can range from cryptocurrencies, such as Bitcoin, which enables peer-to-peer transactions without a central authority, to decentralized finance platforms, supply chain management systems and digital identity verification services. Applications are designed to meet the direct needs of end-users or industries, showcasing the practical utility of blockchain technologies (BCTs). [12]

### **Infrastructure Application Protocols**

Delving deeper, infrastructure application protocols serve as the backbone of the blockchain ecosystem, providing foundational services to other blockchain-based applications rather than directly serving end consumers. These protocols are akin to Business-to-Business (B2B) services that enable decentralized applications (dApps) and smart contracts to perform their functions effectively. Infrastructure is categorized into sub-categories such as “shared compute”, “oracles”, “scaling solutions”, “Internet of Things (IoT)” and miscellaneous tools. For instance, “shared compute” involves a network of computers working together to perform specific tasks, like Filecoin and Arweave, which provide decentralized storage solutions. Oracles, such as Chainlink and Augur, fetch data external to the blockchain and make it available to smart contracts, while “scaling solutions” like Polygon and OMG Network improve transaction throughput on the blockchain. [10]

### **Blockchain Layered Structure**

The architecture of blockchain technology is designed across multiple layers, each serving a distinct purpose in ensuring the network's efficiency and security. This structure addresses the blockchain scalability challenge, facilitating efficient data management and transaction processing. The five main layers include:

1. Data Layer: Contains the actual data transferred and stored within the blockchain, utilizing cryptography to secure transactions.
2. Hardware/Infrastructure Layer: Comprises the physical devices and network that run the blockchain, including computers and servers.
3. Network Layer: Ensures communication between nodes in the blockchain network, allowing for transaction handling and block discovery.
4. Consensus Layer: Essential for achieving agreement across the network on the validity of transactions and the addition of new blocks.
5. Application Layer: The user-facing layer, including smart contracts, dApps and chain code, which users interact with.

Those layers highlight the complexity and scalability solutions inherent in blockchain design. This layered structure supports the development of a robust infrastructure capable of accommodating a wide variety of applications, thereby ensuring the blockchain's adaptability and resilience. [11]

### **Technical Requirements for Blockchain Infrastructure**

Developing blockchain infrastructure involves a range of technical considerations, from selecting the appropriate blockchain platform to designing nodes and configuring blockchain instances. The choice of platform is critical and should align with the desired consensus mechanism, whether it's Proof of Work (PoW), Proof of Stake (PoS), or others. The design of nodes—whether they are part of a private, public, or hybrid blockchain—requires careful consideration of the operating environment and hardware specifications. Furthermore, the development of APIs and the user interface are crucial steps in making blockchain technology accessible and usable. Incorporating advanced technologies such as AI, biometrics and data analytics can significantly enhance the capabilities of blockchain solutions. [13]

### **Differentiating Between Blockchain Applications and Infrastructure**

To effectively differentiate between the two types of blockchain solutions, applications and infrastructure, within the dataset, we must consider their layer of operation, target audience and functionality. Infrastructure provides the necessary capabilities for applications to function. Applications are designed for specific interactions and uses by end-users. This understanding clarifies the distinction between the foundational aspects of blockchain technologies (BCTs) (infrastructure) and its practical implementations (applications), facilitating a comprehensive understanding of the versatility and potential of blockchain technology (BCT) for a wide array of applications and innovations.

This paper has elaborated on the functionalities and distinctions between blockchain applications and infrastructure, providing insights into their roles within the blockchain ecosystem. By introducing the dataset of multiple blockchain solutions, categorized into applications and infrastructure, this paper aims to enhance the understanding of blockchain technologies (BCTs) and their potential for innovation across various applications and industries.

## **2.4. Domains of applications**

In the ever-evolving landscape of digital technology, blockchain emerges not just as a groundbreaking innovation, but as a versatile foundation capable of transforming a plethora of sectors. Its adaptability is not merely a characteristic, but the core strength of blockchain, enabling it to enhance various domains of our society.

Blockchain's significant impact on the economy is evident in its ability to secure data and enhance transparency. Blockchain redefines the standard of secure and transparent economic processes by fortifying financial transactions and revolutionizing supply chains. Its immutable ledger and consensus mechanisms instill a new level of trust and efficiency, setting a standard for how economic interactions are conducted and recorded, a theme that is explored in depth throughout this paper.

Moving beyond its economic implications, blockchain's versatility extends to vital sectors such as health and education. Healthcare systems benefit from enhanced data management, ensuring the security and privacy of sensitive patient information. Similarly, in education, blockchain's ability to authenticate and securely store academic credentials paves the way for a more reliable and streamlined verification process, reflecting the technology's potential to redefine the administration of public services, as will be seen again later in the detailed discussions of this paper.

The inherent transparency and accountability of blockchain align perfectly with the goals of sustainability and ecological conservation. Projects like 'Responsible Box' [15] and 'DOVU' [16] show how blockchain can track carbon emissions, support eco-friendly initiatives and promote sustainable urban planning. The close relationship between blockchain and sustainability highlights the

technology's role in tackling global environmental challenges and advancing Sustainable Development Goals (SDGs), a connection that is reiterated and elaborated upon in various sections of this paper.

Furthermore, blockchain acts as a catalyst for creating more inclusive economic frameworks. Its decentralized nature breaks down traditional barriers to financial services, offering pathways to financial inclusivity and reshaping the landscape of access to capital. This democratization of financial services is not just a feature of blockchain but a transformative shift towards a more equitable economic system.

In the realm of public transportation and urban mobility, the application of blockchain technology symbolizes its potential to enhance operational efficiency and foster sustainable urban mobility. By ensuring secure and transparent data management, blockchain can streamline transit systems, reduce congestion and contribute to the development of smarter, more sustainable cities. This application is a testament to blockchain's multifaceted nature, as it intersects with various sectors and themes discussed in the paper.

In conclusion, the domains of blockchain applications are as diverse as they are impactful, addressing critical challenges and unlocking new potentials across various sectors. As this technology continues to evolve, it promises to be a cornerstone in the edifice of our future digital and physical infrastructures. The myriad of applications underscored in this introductory section is just the beginning of a transformative journey, highlighting blockchain's role as a multifaceted and dynamic force in the contemporary technological era.

## 2.5. Generations of blockchain

Blockchain technology, serving as a model for decentralized and secure data management, has significantly evolved since its beginning. This evolution can be understood through the study of different generations of blockchain, each marking a leap in the technology's capability, application and complexity.

The foundation of blockchain technology was laid with the creation of Bitcoin, described as a "Peer-to-Peer Electronic Cash System" by Satoshi Nakamoto in 2008, marking the genesis of what we now know as the first generation of blockchain. This generation was characterized by its revolutionary approach to decentralized financial transactions, enabling secure peer-to-peer transactions without the need for a central authority. This period saw the introduction of concepts like proof-of-work (PoW) to achieve consensus among network nodes, a mechanism that, while ensuring network integrity and security, was also criticized for its energy-intensive nature. [7]

The second generation of blockchain was heralded by the introduction of Ethereum, which extended the use of blockchain beyond simple financial transactions through the implementation of smart contracts. These self-executing contracts with the terms directly written into code broadened the scope of blockchain into various fields such as finance, healthcare and real estate, among others. This generation addressed some limitations of the first generation by offering more versatility and efficiency. [9]

Emerging as a response to the limitations of previous generations, the third generation of blockchain aims to tackle issues such as scalability, interoperability and sustainability. Projects like "Cardano" and "Polkadot" exemplify this generation, focusing on creating blockchain protocols that are more adaptable and can interact with each other. This generation is characterized by its efforts to create a more interconnected and efficient blockchain ecosystem. [9]

Across these generations, the underlying principle of decentralization, transparency and immutability remains consistent. However, the approach to consensus mechanisms has seen a shift from PoW to more energy-efficient alternatives like proof-of-stake (PoS), addressing concerns regarding the environmental impact of blockchain technology (somethings that can be related to the SDGs, the goals that has been examined later in this paper). [7]

In the context of this study, the evolution of blockchain can be observed in the varied applications of this technology in different industries, each leveraging the specific features of the generation it is built upon. As outlined in the previous chapters, the data collected for this paper

reflects this evolution, showing a trend of increasing complexity and capability in blockchain applications.

In conclusion, the study of blockchain generations reveals a technology that is rapidly evolving to meet the changing needs of the digital world, the varied needs that have been examined throughout this paper and plenty more that already exist or that will be created in the future. From simple financial transactions to complex decentralized applications, blockchain technology has shown a remarkable ability to adapt and innovate. As this technology continues to evolve, it promises to offer new solutions to the enduring challenges of security, privacy and efficiency not only in digital transactions but across the multiple sectors examined in this paper and many more.

## 2.6. Benefits and barriers

Blockchain technology offers a myriad of benefits but also faces significant barriers to widespread adoption. The benefits, rooted in its unique architecture, include enhanced security, improved transparency and increased efficiency in transactions. Those are some recurring benefits across multiple BCTs (Blockchain Technologies), including many of the BCTs presented in the data of this paper.

Security is paramount in blockchain's design. The decentralized nature and cryptographic protection of each block make the data tamper-resistant, addressing concerns about data integrity and fraud. Transparency is another cornerstone, with blockchain, every transaction is visible and verifiable by all network participants, fostering trust and accountability. [7]

Efficiency is achieved through the elimination of intermediaries in transactions, streamlining processes and reducing costs, particularly in industries like finance and real estate. The ability of smart contracts to automate and enforce agreement terms further enhances this efficiency, opening up various applications beyond mere financial transactions. [7][9]

However, blockchain also encounters barriers. Scalability issues arise as the size and number of transactions grow, impacting performance and speed. Interoperability between different blockchain systems remains a challenge, limiting the seamless exchange of information across platforms. Furthermore, while the technology promotes transparency and security, these features can also lead to complex regulatory and compliance issues, as the technology often outpaces current legal frameworks. [7]

In the context of this paper, understanding these benefits and barriers is crucial in analyzing the applicability and potential impact of blockchain technology in various sectors. The data collected offers a lens to view how these factors play out in real-world scenarios, shaping the adoption and evolution of blockchain technology.

## **3. Methodological approach**

The research of this paper was based on three research questions and for each one of those a different and distinct methodological approach was used. Each one of those questions with their corresponding methodology contributes distinct perspectives and insights and together they form a comprehensive understanding of the current state and nature of the blockchain technology and also the benefits and problems that come with it.

The first research question is “What are the possible perspectives of analysis?” and is addressed using a method known as “literature review”. This is done through an in-depth analysis of scholarly articles, industry reports and academic publications. This analysis forms the foundation of our exploration into blockchain's role in multiple sectors that we will see later, including financial transactions and its broader implications for transparency and trust. This stage of research highlights blockchain's potential in enhancing data integrity and security across personal, public and financial domains. The “literature review” contributes by offering a theoretical lens to understand blockchain's diverse applications. It highlights that blockchain's utility extends beyond digital currencies (like the famous Bitcoin) and has the potential to revolutionize interactions between individuals, businesses

and governments. This exploration of theoretical frameworks provides a detailed and in-depth understanding of the technology, preparing the groundwork for more detailed explorations.

For the second research question, “What are the different types of BCT solutions?”, a different approach has been employed, the approach used for this question is known as “desk-based research”. This approach transitions from theoretical exploration to practical analysis. It systematically collects and analyzes data from various sources. This phase categorizes and analyzes the functionalities of blockchain's decentralized and distributed ledger systems. It provides a focused examination of blockchain solutions, emphasizing their potential to disrupt traditional business models. This method extends our initial findings, presenting a structured and detailed view of blockchain's applications across different industries and solidifying the insights gained.

The final methodological phase, for the third question “What are the main characteristics of the identified BCT solutions?”, involves data analysis and statistical insight, building upon the qualitative assessments with a quantitative approach. Using statistical tools to examine the data gathered, this phase analyzes various blockchain types, consensus mechanisms and governance models. It offers evidence-based support to our theoretical and practical observations, providing a comprehensive view of the technological readiness, adoption challenges and governance structures within the blockchain ecosystem.

These methodologies collectively present a multi-layered understanding of blockchain technology. Each methodological step, distinct yet interconnected, contributes to a seamless narrative flow. The “literature review” establishes the theoretical base, “desk-based research” provides practical insights and “data analysis” delivers empirical validation. Together, they offer a cohesive and in-depth exploration of blockchain technology, highlighting its transformative potential and the complexities of its applications in the real world. This methodological combination enriches the research and lays a robust foundation for future research in this evolving domain.

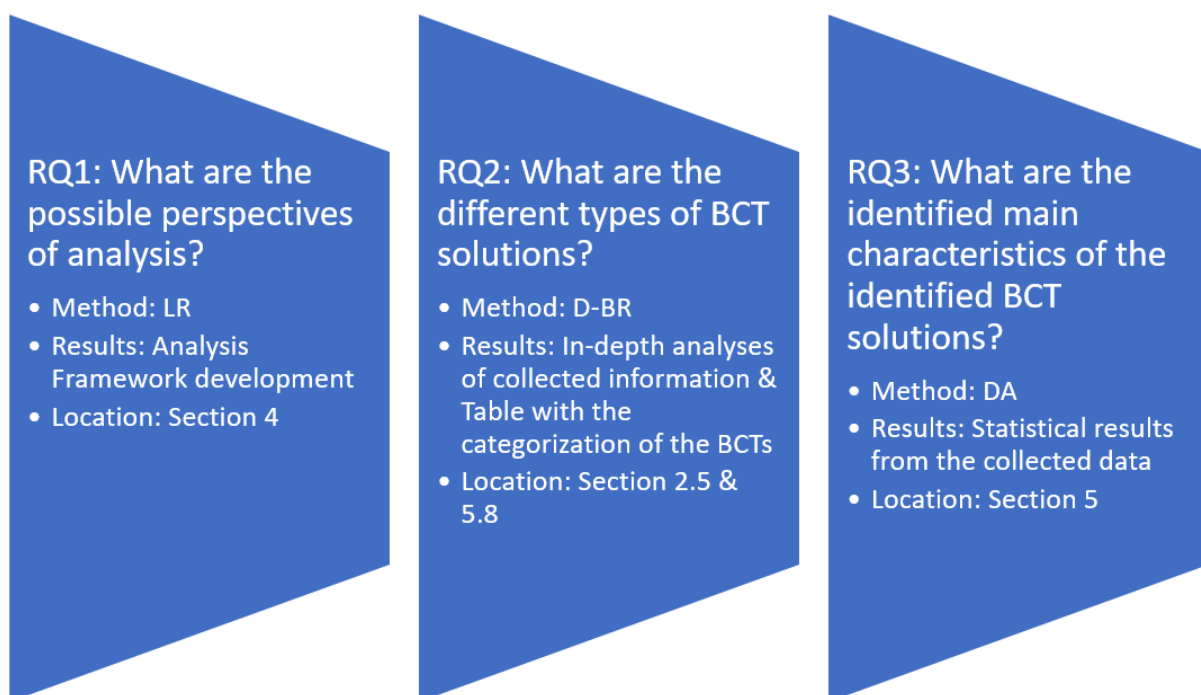


Image 1: Methodological approach 3 RQs

### RQ1: What are the possible perspectives of analysis?

In the initial phase of the research into the dynamic, vast and intricate domain of Blockchain Technologies (BCT), a specific type of research known as “Literature review” was used. This approach had two goals, the first one was to collect some fundamental data, but the second one and the most important one, was the goal of comprehending the various and diverse perspectives of analyses of the existing BCT research. This literature provided the necessary basis for understanding the type of analysis that was required.

The purpose of this “literature review” was to establish a solid foundation for the in-depth analyses and discussions that constitute the core of this research. By meticulously reviewing relevant academic publications, the research aimed to capture a wide array of viewpoints and theoretical frameworks within the BCT field. During this phase, the methodology involved a detailed examination of a multitude of scholarly articles, each contributing a unique perspective to the understanding of BCT. This process entailed not just a summarization of findings but a critical analysis and synthesis of the information gathered. The outcome of this review was vital in shaping the analysis framework presented in this paper.

In conclusion, the literature review of this paper highlighted the diversity and the hidden capabilities of the multiple blockchain technologies developed. While certain aspects, such as the use of BCT for the creation of cryptocurrencies, have been extensively explored, other areas lack that attention and have been heavily ignored. This paper, therefore, tries to find and analyze those aspects, with the use of this “literature review”. The results of this research question are presented in the chapter “4.2. Analytical presentation of the factors”.

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Now, we will see the foundational scholarly works that were collected during the “literature review” and provided the essential data structure for this research. These papers were not just theoretical cornerstones, they offered the concrete parameters and dimensions that formed the dataset for each blockchain analyzed in this study. Their insights and comprehensive frameworks were crucial in identifying the specific attributes and metrics required to assess and compare the practical applications, challenges and innovations of blockchain technology, they were pivotal in defining the perspectives of analysis of the dataset of this paper (the columns of the table with the data). These dimensions form the backbone of the dataset, guiding the data collection and analysis process of this research. This section emphasizes the empirical foundation these papers established, guiding the data collection and analysis process of this research.

Central to initiating the framework of this research was the following paper, which not only provided the initial perspectives of analysis (all the perspectives can be found later in this paper with a lot of detail) but also set the precedent for our investigation. Acting as the cornerstone, this work inspired the methodology and the development of the dataset's primary perspectives of analysis, guiding the expansion and deepening of our analysis through the subsequent inclusion of insights from the papers mentioned thereafter:

- “How Blockchain Technology Changes Government: A Systematic Analysis of Applications” [1]

Provided the initial perspectives:

- BCT type
- TRL
- Application domain (sector)
- Countries

Additional perspectives of analysis that were developed specifically for the research of this paper have been utilized:

- Problems addressed
- SDG connection
- Application level

- Types of solutions (a very important perspective for this paper as explained in previous and later sections)

The following papers contributed significantly to establishing the additional analytical perspectives and gaining additional information and knowledge about them:

1. “Exploring Blockchain Technology for government Transparency: Blockchain-Based public procurement to reduce corruption” [2]  
Provided perspectives:
  - Consensus mechanism
2. “Blockchain Technologies: Opportunities for solving real-world problems in healthcare and biomedical sciences” [3]
  - Provided additional information on the existing perspectives
3. “Blockchain in government: toward an evaluation framework” [4]  
Perspectives provided:
  - Benefits
  - Cost
4. “Blockchain governance in the public sector: a conceptual framework for public management” [5]  
Provided perspectives:
  - Level of governance
  - Types of decisions

These papers collectively provided a multi-dimensional view of the potential and challenges of blockchain technology, significantly shaping the parameters and perspectives of our research analysis.

Furthermore, different papers were used for the research required in the previous chapter on the background of the BCT (Blockchain Technology). Those papers were referenced at the corresponding chapters (the references can be found gathered together at the end of this paper), while this chapter serves as a summary of all the papers used throughout this entire paper gathered in one place. So for the background of the consensus mechanisms, the following three papers were used:

1. A survey on blockchain consensus mechanism: research overview, current advances and future directions [6]
2. Evolution of blockchain consensus algorithms: a review on the latest milestones of blockchain consensus algorithms [7]
3. The Future of Blockchain Consensus [8]

The result of the thorough analysis of those papers can be found in the chapter “2.2 Consensus mechanism background”. As for the results shown in the chapter “2.6 Generations of blockchain” the following papers were used:

1. Evolution of blockchain consensus algorithms: a review on the latest milestones of blockchain consensus algorithms [7]
2. The Evolution of Blockchain: A Bibliometric Study [9]

Notice here that the first paper in this last list is one of the papers that were used in the list above, for the chapter “2.2 Consensus mechanism background”.

### *RQ2: What are the different types of BCT solutions?*

In the second phase of my research for this paper, I employed a different type of research than the one I used in the first part, here I used something called a “desk-based” research. This type of research, also known as secondary research, involves the systematic collection and analysis of existing information from various sources. This method primarily focuses on gathering data from published materials, such as reports, articles, databases and online resources, rather than collecting original data through experiments or surveys.

The focus of my research was on blockchain technologies that provide practical services and assistance in diverse areas and industries. This exploratory approach allowed me to delve into the wide-ranging applications of blockchain technology, particularly those offering innovative solutions and tangible benefits to everyday life and various sectors. Selecting blockchain solutions for analysis was guided by their potential to contribute meaningfully in specific domains, rather than adhering to rigid criteria. This strategy enabled the inclusion of a diverse array of blockchain technologies in the research, each showcasing different ways they could enhance or revolutionize standard practices and services.

A key aspect of “desk-based” research is its ability to collect and interpret information from a multitude of sources, offering a comprehensive perspective on the subject. However, one challenge in this process was accessing detailed information about some lesser-known blockchain technologies, leading to undisclosed data points in certain instances, something that can be seen in the data of this paper. Despite these challenges, the “desk-based” research method was crucial for gaining further insights into the broad applications of blockchain technology, further than we have seen so far. It was particularly revealing in showing the versatility of blockchain solutions in various facets of daily life and across numerous industries, something that we have already seen while analyzing the vast capabilities of this technology.

In conclusion, this approach to research not only highlighted the extensive applicability and potential impact of blockchain solutions beyond the realm of cryptocurrencies, something that has been mentioned before in this paper, but also set the groundwork for future in-depth studies into specific blockchain applications. The method proved effective in synthesizing information from diverse sources, thus enabling a deeper exploration of the untapped potential of blockchain technology in different fields.

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The methodology adopted for addressing RQ2, the desk-based research, also guided the classification of the BCTs of the dataset into applications and infrastructure, one of the most important parts of the research conducted for this paper. This research, informed by the distinctions between application-oriented and infrastructure-oriented BCTs as detailed in the previous chapter “2.4. Types of solutions”, utilized a comprehensive review of literature and existing blockchain technologies. This approach allowed for a methodical evaluation of each BCT presented in the dataset, ensuring that the differentiation into applications or infrastructure was grounded in a robust analysis of their roles and functionalities within the blockchain ecosystem. The classification of BCTs, therefore, was a detailed process that benefited from the depth of the “desk-based” research, highlighting its effectiveness in enhancing the structure and clarity of the study's findings. This meticulous process highlights the importance of a thorough and informed analysis, facilitated by the “desk-based” research, in categorizing the diverse array of blockchain technology solutions (BCT solutions) present in the dataset of this paper. The results of the classification of the BCTs from the dataset can be found in chapter “5.8. Application / Infrastructure”, where the type of each BCT of the dataset can be found.

### *RQ3: What are the main characteristics of the identified BCT solutions?*

This section focuses on analyzing the data gathered from the research of this paper, the results of the “desk-based” research, which includes various blockchain solutions. To deepen the analysis, the research methodology was expanded to include “data analysis”, the method used for this research question. This analytical approach involved the meticulous examination and interpretation of the collected data, employing statistical tools within Excel to identify patterns, frequencies, and significant trends within the blockchain solutions. For each blockchain technology the research included various specific attributes, the results will be presented in a table, where each column is one of those attributes. Each entry provides detailed insights into specific blockchain implementations. For this part of the research each entry will be examined, focusing on quantifiable attributes and their occurrences. Statistical tools within Excel are used to identify patterns and frequencies, offering a systematic approach to understanding the dataset.

A significant observation regarding the data is the widespread application of blockchain across diverse sectors. While this has been noted previously, it's important to emphasize its ubiquity

and the breadth of its impact. This analysis provides a granular look at how blockchain technology permeates various industries. A key insight from the data is the alignment of many blockchain solutions with Sustainable Development Goals (SDGs). This finding underscores blockchain's potential in addressing global challenges, highlighting its role in initiatives such as supply chain transparency and financial inclusivity. Statistical analysis reveals trends and commonalities among the blockchain solutions. This includes the prevalence of certain consensus mechanisms and the distribution of blockchain types (public, private, consortium). These patterns offer an understanding of current preferences and practices in the blockchain space.

The analysis concludes by synthesizing these findings, providing a comprehensive view of the current state of blockchain technology. It highlights the technology's versatility and potential contributions to societal and economic advancements, especially in relation to the SDGs.

## 4. Analysis Framework

In this pivotal chapter, the meticulously developed analytical framework is unveiled, crafted to address the first research question (RQ1): "What are the possible perspectives of analysis?". This framework stands as the cornerstone of this paper's research, intricately designed to dissect and examine the complicated and rich nature of the BCTs. It synthesizes a multitude of dimensions of the BCTs, including their connection to the Sustainable Development Goals (SDGs), which like it was mentioned before, is a very important part of this paper. This chapter not only serves as a foundation for the comprehensive assessment of blockchain applications but also links these diverse aspects to real-world implications and future potential. Through this framework, the paper aims to provide an in-depth understanding of blockchain technology's versatile applications and their transformative impact across various sectors. By methodically dissecting each element, we will navigate the complexities of blockchain technologies, offering insights into their current state and future prospects. This approach ensures a holistic view, grounding our analysis in both theoretical understanding and practical relevance.

### 4.1. Analysis Framework Overview

The following table briefly presents the aspects of the analysis framework which is built for governmental solutions or solutions that are applied at any government level.

Table 1: analysis framework overview

| <b><u>Title</u></b>                | <b><u>Description</u></b>                                                                                                                                                                                      | <b><u>Measurement</u></b>                                                                                                                                                                     |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b><u>BCT Type</u></b>             | Blockchain types vary based on accessibility and governance structures, commonly categorized into public, private and hybrid blockchains, each offering distinct levels of transparency, security and control. | <ul style="list-style-type: none"> <li>• Public</li> <li>• Private</li> <li>• Hybrid</li> </ul>                                                                                               |
| <b><u>Consensus Mechanisms</u></b> | Protocols that ensure all participants in the blockchain network agree on the validity of transactions, crucial for maintaining the integrity and security of the distributed ledger.                          | <ul style="list-style-type: none"> <li>• Proof of stake</li> <li>• Proof of authority</li> <li>• Proof of carbon</li> <li>• Proof of agreement</li> <li>• Custom</li> <li>• Others</li> </ul> |
| <b><u>TRL</u></b>                  | "Technology Readiness Level"<br>How ready is this technology to be used in a real                                                                                                                              | Levels 1 - 9                                                                                                                                                                                  |

|                                           |                                                                                                                                                                                                                                           |                                                                                                                                                                                                   |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | environment                                                                                                                                                                                                                               |                                                                                                                                                                                                   |
| <b><u>Cost</u></b>                        | Simply how much it cost to use this blockchain technology                                                                                                                                                                                 | Price of use                                                                                                                                                                                      |
| <b><u>Application Domain (Sector)</u></b> | Refers to the various sectors and industries where blockchain technology is applied, ranging from finance and healthcare to supply chain management and voting systems, demonstrating its versatility and transformative potential.       | Different sectors of society and everyday life                                                                                                                                                    |
| <b><u>Level of Governance</u></b>         | Pertains to the rules, policies and procedures that dictate how the blockchain operates, varying from strict and centralized control in private blockchains to more democratic and distributed governance in public blockchains.          | <ul style="list-style-type: none"> <li>• Micro</li> <li>• Meso</li> <li>• Macro</li> <li>• Combinations</li> </ul>                                                                                |
| <b><u>Types of decisions</u></b>          | Involve actions and resolutions such as transaction validation or protocol upgrades, directly influenced by the blockchain's level of governance, highlighting the interplay between decision-making processes and governance structures. | Various/diverse                                                                                                                                                                                   |
| <b><u>Benefits</u></b>                    | Encompass the wide array of advantages offered by blockchain technology, such as enhanced transparency, increased security, reduced costs and improved efficiency, contributing to its transformative impact across various sectors.      | Various/diverse                                                                                                                                                                                   |
| <b><u>Problems Addressed</u></b>          | It highlights blockchain's role in tackling a range of challenges, it demonstrates the technology's capacity to bring transparency, streamline operations and optimize systems across various domains.                                    | Various/diverse                                                                                                                                                                                   |
| <b><u>SDG Connection</u></b>              | Refers to how blockchain applications align with and contribute to the United Nations Sustainable Development Goals, addressing global challenges such as poverty, inequality, climate change and sustainable economic growth.            | 17 SDGs from the UN                                                                                                                                                                               |
| <b><u>Countries</u></b>                   | What countries have implemented this technology or have allowed this technology to be implemented by someone under their supervision.                                                                                                     | Countries applying the solutions                                                                                                                                                                  |
| <b><u>Application Level</u></b>           | Reflects the operational scope of blockchain integration showcasing its adaptability to diverse governance and operational contexts.                                                                                                      | <ul style="list-style-type: none"> <li>• Global</li> <li>• Regional</li> <li>• Municipal</li> <li>• Enterprise</li> <li>• International</li> <li>• Organizational</li> <li>• Community</li> </ul> |
| <b><u>Types of</u></b>                    | In the context of BCTs it refers to the categorization into                                                                                                                                                                               | Application/                                                                                                                                                                                      |

|                         |                                                                                                                                          |                |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------|----------------|
| <b><u>solutions</u></b> | applications, which are user-focused services built on blockchain and infrastructure, the underlying technology enabling these services. | Infrastructure |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------|----------------|

## 4.2. Analytical presentation of the factors

### 4.2.1. BCT Types

The widely known blockchain technology has evolved to the point that all blockchain applications created can be categorized into three main categories: public, private and hybrid, each serving diverse needs across various industries. Each type comes with unique attributes and serves different needs in various sectors. They differ significantly in their structure, governance and intended applications, reflecting the versatility and adaptability of this groundbreaking new technology, the blockchain technology.

#### Public Blockchains: the epitome of decentralization

Public blockchains, with some of the most notable and famous ones being “Bitcoin” and “Ethereum” as prime examples, stand out as the most recognizable forms of blockchain technology. These platforms are characterized by their open and decentralized nature, allowing anyone to participate without restrictions. This openness fosters an environment of unparalleled transparency, which is the main reason why they were used to create digital forms of currencies, the cryptocurrencies. This combination of unique and unseen before openness and transparency has facilitated the creation of digital currencies, where each transaction is visible to all network participants, offering unparalleled safety and basically zero corruption. The security of these blockchains is maintained through consensus mechanisms, with one of the most famous ones being “Proof of work” (PoW), the consensus mechanism used by the famous “Bitcoin” and other equally known ones like “Proof of Stake” (PoS), which require network participants to agree on the validity of transactions. However, the very features that make public blockchains attractive also introduce significant challenges. The decentralized validation process can lead to scalability issues, as the growing number of transactions increases the load on the network, potentially causing delays and higher transaction fees. Furthermore, the energy-intensive nature of certain consensus mechanisms, particularly Proof of Work, has raised environmental concerns. This aspect of public blockchains is increasingly scrutinized in the context of the United Nations' “Sustainable Development Goals” (SDGs), especially “Goal 7: Affordable and Clean Energy” and “Goal 13: Climate Action”. The substantial energy consumption and the resulting carbon footprint of these blockchains conflict with the global objectives of reducing energy use and mitigating climate change. As a result, there's a growing incentive within the blockchain community to develop more energy-efficient technologies and practices that align with these broader environmental and sustainability goals, emphasizing the urgent need to balance technological advancement with ecological responsibility. Acknowledging the significance of these concerns, this paper takes a deliberate approach in examining how each blockchain solution aligns with those “SDGs”. Throughout the analysis, the corresponding “SDGs” for each blockchain solution will be specifically highlighted, illustrating their potential impacts and contributions towards achieving these global objectives. This inclusion aims to provide a comprehensive understanding of the blockchain technologies not only in technological terms but also in their broader socio-environmental context and their impact on the lives of everyone in the world.

#### Private Blockchains: efficiency and control in a secured environment

In contrast to the open nature of public blockchains, we also have private blockchains that offer a more controlled and secured environment for certain situations or environments that require it. These blockchains restrict access to predetermined individuals or organizations, thereby creating a closed, controlled and safe network. This restricted access model provides safety and a higher degree of privacy and data protection, which is particularly appealing to corporate entities that handle

sensitive information. This restricted access model provides a higher degree of privacy and data protection, which is particularly appealing to corporate entities that handle sensitive information. However, the centralized aspect of private blockchains can be a double-edged sword. While it allows for greater control over the network, private blockchain's deviation from the decentralization principle contrasts starkly with the reasons behind the success of many well-known blockchains. The decentralized nature of these prominent blockchains and the applications leveraging blockchain technology is a highly sought-after characteristic, valued for the unique benefits it brings. The decentralization not only fosters trust among users but also enhances security and transparency, key elements that have driven the widespread adoption and acclaim of blockchain technology. On the other hand the centralization could potentially lead to vulnerabilities in terms of security and resistance to data manipulation, contrasting with the trustless environment of public blockchains.

#### Hybrid Blockchains: Merging Public and Private Characteristics

The third and final type of blockchains that we will analyze in this paper is the hybrid one, which can be seen as the combination of the other two mentioned above. Hybrid blockchains emerge as an innovative solution, merging the best features of both public and private blockchains. These blockchains offer a dual structure that allows for controlled access in certain aspects while maintaining a level of openness in others, thus taking the best of both private and public and combining them into a new type of blockchain. Such a design enables organizations to keep some parts of their transactions private while leveraging the trust and transparency of public blockchains for others. This versatility makes hybrid blockchains particularly appealing for businesses that require confidentiality for internal transactions while still needing to interact or record data on a public blockchain. Despite their advantages, hybrid blockchains present unique challenges, primarily in their design and governance. Creating a blockchain that effectively balances private and public elements requires careful planning and a clear governance structure to ensure that the needs of all stakeholders are met and that the integrity of the blockchain is maintained.

#### Conclusion: Selecting a Blockchain tailored to fit specific needs

In conclusion, the differentiation among public, private and hybrid blockchains underlines the importance of understanding their unique attributes and potential applications. Public blockchains are best suited for scenarios requiring maximum transparency and decentralization, such as in the creation of cryptocurrencies and open-source projects. Private blockchains, with their emphasis on privacy and control, are ideal for enterprise solutions where internal processes and sensitive data need to be protected. Hybrid blockchains, with their flexible nature, cater to businesses that require a combination of confidentiality and transparency. As we will explore in the forthcoming data, different blockchain implementations leverage these three types based on their specific operational requirements and strategic objectives. Understanding of the different types of blockchains is crucial for organizations aiming to leverage this technology to its fullest potential, ensuring that the chosen blockchain aligns with their specific business needs and objectives. The selection of a blockchain type should, therefore, be guided by the specific requirements of the use case, considering factors such as the desired level of decentralization, privacy, scalability and security. Each blockchain implementation that we are going to see in the data provided in this paper, has different needs and offers different benefits, therefore has different needs and requirements making the type of blockchain that fits different for each one of them.

#### 4.2.2. Consensus Mechanisms

Consensus mechanisms are a vital element in blockchain technology, providing a method for achieving agreement among distributed nodes, or participants, on the state of a blockchain. These mechanisms are essential in maintaining the integrity and reliability of a decentralized network. They play a critical role in ensuring that all participants have a consistent view of the ledger, which is vital for the ledger's immutability and trustworthiness. These mechanisms are designed to achieve agreement, or consensus, among distributed nodes (participants) regarding the state of the blockchain, which is critical for maintaining a unified and tamper-resistant ledger of transactions.

The primary purpose of a consensus mechanism is to allow for the secure and fair updating of the blockchain, even in the absence of trust among the network participants. This is achieved by ensuring that all changes to the ledger are validated according to a set of rules agreed upon by the network. The consensus mechanism ensures that each participant's copy of the distributed ledger is the same, thereby preventing fraudulent transactions and double-spending.

In a decentralized network, where there is no central authority, consensus mechanisms are crucial for coordinating the system. They provide a way to achieve a unified agreement on the state of the ledger among independent nodes, each of which may have different interests or may not trust each other. This is particularly challenging in an environment where nodes can join or leave the network at will and where they might be spread across the globe, with varying levels of computing power and network connectivity.

Consensus mechanisms also play a role in network security. They are designed to resist various types of attacks, such as those by malicious actors who may try to manipulate the ledger or disrupt the network. By requiring certain conditions to be met for a transaction to be added to the blockchain, these mechanisms make it prohibitively expensive or technically infeasible for attackers to alter the blockchain's history or to create fraudulent transactions.

Additionally, consensus mechanisms can influence other characteristics of the blockchain, such as its scalability, speed and environmental impact. The choice of a particular consensus mechanism can significantly affect the network's performance and the types of applications for which it is best suited. For instance, some mechanisms prioritize energy efficiency, while others focus on maximizing transaction speed or ensuring the highest degree of decentralization. That can have a direct connection to the SDGs that were mentioned previously.

Each consensus mechanism has its own strengths and weaknesses and the choice of a particular mechanism depends on the specific requirements of the blockchain network, such as speed, security, decentralization and energy efficiency. The selection of a consensus mechanism is a critical decision that can significantly impact the performance and security of a blockchain network. That is why in this paper, there are several different consensus mechanisms for the various, different projects mentioned in the data.

In conclusion, consensus mechanisms are a foundational aspect of blockchain technology. They enable a distributed set of nodes to maintain a secure and unified ledger in a decentralized environment. By providing a means for network participants to agree on the state of the ledger, these mechanisms are vital for the integrity, security and functionality of blockchain networks. Their selection and implementation are critical decisions that can define the overall characteristics and capabilities of a blockchain.

In this paper we are going to see several different consensus mechanisms, some of them are very well known and widely used across multiple blockchain applications and some others are lesser known ones and even some custom ones, created for the specific needs of the blockchain applications mentioned in this paper.

### **Primary Types of Consensus Mechanisms**

#### **Proof of Work (PoW)**

- **Description:** PoW, a consensus mechanism popularized by Bitcoin, involves miners solving complex cryptographic puzzles to validate transactions and add new blocks to the blockchain. The miner who first solves the puzzle is permitted to add a block to the chain and receives a reward in cryptocurrency.
- **Advantages:**
  - **High Security:** Altering the blockchain is prohibitively difficult and costly, as it would require redoing the PoW for all subsequent blocks.
  - **Scalability in Transaction Volume:** Despite common perceptions, PoW can handle several million transactions per day and has potential pathways to scale up for accommodating billions of transactions.
  - **Potential for Energy Efficiency:** When considering the overall security, decentralization and robustness provided, PoW, in certain contexts, can be viewed as

energy-efficient, especially when considering the energy cost per transaction and the system's long-term sustainability.

- **Disadvantages:**

- **Computational Power and Energy Consumption:** The process of solving cryptographic puzzles requires significant computational resources, leading to high energy consumption, which is a concern from an environmental and economic perspective.
- **Per-Transaction Scalability:** PoW is often critiqued for its limited transaction processing capability per second, especially when compared to traditional centralized systems like Visa. This can lead to slower transaction confirmations and higher transaction fees during peak times.

### **Proof of Stake (PoS)**

- **Description:** In PoS, validators are chosen based on their stake in the cryptocurrency. It eliminates mining, favoring a system where the creation of new blocks is proportional to one's existing stake.
- **Advantages:** More energy-efficient and scalable than PoW.
- **Disadvantages:** Potential for centralization due to favoring those with larger stakes.

### **Delegated Proof of Stake (DPoS)**

- **Description:** DPoS is an evolution of PoS, where token holders vote for a few delegates responsible for validating transactions and creating blocks.
- **Advantages:** Faster transactions and less energy consumption than PoW.
- **Disadvantages:** Centralization risks due to the power of delegates.

### **Proof of Authority (PoA)**

- **Description:** PoA is a reputation-based consensus mechanism where transactions and blocks are validated by approved accounts, known as validators. Trust is placed in these validators' identity and reputation.
- **Advantages:** High transaction throughput and more energy-efficient.
- **Disadvantages:** Centralization concerns, as the network depends on a few validators.

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### **Other and Custom Consensus Mechanisms**

Besides these primary mechanisms, there are lesser-known and custom consensus protocols designed to address specific needs. For example, "Proof of Carbon" is a custom mechanism focusing on environmental impact, where the consensus process is tied to carbon credits or other eco-friendly initiatives. This approach represents a growing trend in blockchain technology to align with broader social and environmental goals.

### **Proof of Carbon**

The "Proof of Carbon" mechanism, as introduced by DOVU and utilized in conjunction with Hedera Hashgraph, represents an innovative approach in the blockchain domain, particularly in addressing environmental concerns associated with traditional blockchain technologies.

### **Challenges with Traditional Blockchain Technologies**

Traditional blockchain technologies, particularly those utilizing the Proof of Work (PoW) consensus mechanism, like Bitcoin and Ethereum, face significant challenges related to environmental impact due to their high energy consumption. The PoW mechanism also leads to high and unpredictable transaction costs, making on-chain solutions for micropayments and reward mechanisms impractical and environmentally harmful.

### **DOVU's Approach with Proof of Carbon**

One of the blockchains mentioned in the data of this paper is “DOVU”. In response to the challenges mentioned above, DOVU uses the “Proof of Carbon” mechanism. This system records and publicly stores information every time DOV tokens are rewarded to a user through their API. The intent of this mechanism is to transparently display the distribution and assignment of carbon through the DOV token. DOVU's “Proof of Carbon” uses the “Hedera Consensus Service (HCS)” backed by Hedera Hashgraph. This approach is noted for its extremely low environmental and economic costs, adding trust to systems without passing the cost to the user. Hedera is also included in the data of this paper as a separate entity. [16]

### Technical and Environmental Benefits

This mechanism provides a scalable solution for verifying transactions that indicate the transfer of carbon using the DOVU API. It significantly reduces the transactional cost, making it feasible for micro-payments related to carbon offsetting. The environmental impact of blockchain technologies is an important part of this paper and as mentioned before it focuses on the relation of each blockchain to the environment through the SDGs.

One of the unique aspects of DOVU's approach is the focus on soil as a key element in carbon offsetting. The project aims to incentivize farmers to adopt high-quality farming practices through additional income. DOVU is building a decentralized marketplace for farmers and landowners to offer carbon-certified areas of land, verified through soil carbon sequestration. These areas are exchanged for unique non-fungible tokens (NFTs) that include metadata like the exact location of the land. The system ensures accountability and eliminates the carbon double-spend problem, making it a promising solution for businesses and enterprises to meet their carbon reduction targets, which are often written into legislation. [16]

### CONCLUSION

The “Proof of Carbon” mechanism by DOVU, in conjunction with Hedera Hashgraph, represents a significant innovation in blockchain technology, addressing the environmental concerns of traditional blockchain technologies and offering a scalable, low-cost solution for carbon offsetting. This approach not only mitigates the environmental impact but also opens new avenues for economic opportunities, especially in agriculture and carbon trading markets. This innovation aligns with the growing global emphasis on sustainable practices and could potentially set a new standard in the blockchain and cryptocurrency sectors.

[63] [64] [65] [67]

### Proof of state

The “Proof of State” consensus mechanism, as explained in the “Universa” blockchain whitepaper, operates as follows:

- Primary Function of “Universa” Nodes: The core function of the “Universa” Nodes is to execute contracts and verify the state of the blockchain.
- Avoidance of Traditional Mining: Unlike traditional blockchain technologies that utilize mining processes, “Universa” eliminates the need for such energy-intensive and time-consuming activities. This is achieved by not relying on mining techniques that are deemed inefficient in terms of energy and computational resources.
- Permission to Create New Blocks: In the “Universa” blockchain, permission to create new blocks is granted through participation as a licensed node. This is a significant departure from the mining-based approach where new blocks are created through solving complex computational puzzles.
- State Change Verification: A state change within the “Universa” blockchain can occur at any time and is verified by a trusted actor. This process is often completed and approved by consensus in less than ten milliseconds, even on a large scale. This implies a highly efficient and rapid verification process.

- Asynchronous Contract Execution: Each contract within the “Universa” system maintains its own chain of state. This allows contracts to perform actions asynchronously, meaning they can operate independently without blocking or affecting other contracts.
- Directed Acyclical Graph (DAG): The collective changes of state across all contracts form a Directed Acyclical Graph (DAG). This DAG constitutes the blockchain itself in the Universa system. The use of a DAG allows for a more efficient, scalable and faster processing of transactions compared to traditional linear blockchain structures.

[68]

#### 4.2.3. TRL (Technology Readiness Level)

Technology Readiness Level (TRL) is a system used to assess the maturity level of a particular technology. Originally developed by NASA in the 1970s, the TRL framework has become a standard evaluation tool used across various industries, including aerospace, defense and energy. The primary purpose of TRL is to provide a consistent and standardized measure of technology maturity, helping both developers and potential adopters understand the readiness of a technology for implementation or further development.

The TRL framework consists of nine levels, each representing a different stage in the development of a technology, from concept (level 1) to fully mature (level 9): [62]

1. **Basic principles observed and reported:** This is the lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. **Technology concept and/or application formulated:** Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions.
3. **Analytical and experimental critical function and/or characteristic proof-of-concept:** Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. **Component and/or breadboard validation in laboratory environment:** Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
5. **Component and/or breadboard validation in relevant environment:** Fidelity of the technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. **System/subsystem model or prototype demonstration in a relevant environment:** Representative model or prototype system, which is well beyond the breadboard stage, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. **System prototype demonstration in an operational environment:** Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space.
8. **Actual system completed and qualified through test and demonstration:** Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.

9. **Actual system proven through successful mission operations:** Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

#### **Significance of TRL in Blockchain Technology**

In the context of blockchain technology, TRL serves as a crucial gauge for understanding the stage of development and readiness for practical application. Blockchain technologies, being diverse and evolving rapidly, can be at various TRLs:

- **Early Stage (TRL 1-3):** This includes fundamental research on blockchain algorithms, consensus mechanisms and encryption technologies. At this stage, the focus is on theoretical development and small-scale experimentation.
- **Development Stage (TRL 4-6):** Here, blockchain technologies begin to take form as prototypes. This may involve the integration of blockchain with other technologies, like IoT or AI, in a lab environment or controlled settings.
- **Maturation and Implementation Stage (TRL 7-9):** At these levels, blockchain solutions are deployed in real-world scenarios. This involves testing in operational environments, addressing scalability, security and interoperability challenges and ultimately leading to widespread adoption and integration into existing systems.

Understanding the TRL of different blockchain technologies is vital for assessing their readiness for deployment and integration into various applications. This framework helps in identifying the risks and potential of these technologies at different stages of their development, guiding both researchers and industry stakeholders in making informed decisions about investment, research focus and adoption strategies. The data presented in this paper presents a detailed and systematic analysis of multiple blockchain technologies, each annotated with its corresponding TRL. This data serves as a foundational resource for understanding where each technology stands in terms of development and readiness for practical application.

The meticulous categorization of blockchain technologies in this dataset, aligned with their respective TRLs, offers invaluable insights into their current capabilities, potential for growth and areas requiring further research and development. As seen in the data of this paper, it becomes evident that blockchain technologies are at diverse stages of maturity, ranging from theoretical constructs to fully operational systems. This differentiation is crucial for stakeholders, developers and researchers in making informed decisions about investment, development priorities and strategic planning for future implementations.

The mapping of TRLs to individual blockchain technologies, as outlined in the data of this paper, not only highlights the progress made in the field but also underscores the journey ahead towards achieving more advanced, secure and scalable blockchain solutions. It is through such detailed and methodical analysis that the true potential of blockchain technology can be harnessed, paving the way for innovative applications and transformative advancements across various sectors.

#### **4.2.4. Cost**

The cost structure of the blockchain solutions, whether they are public or private, varies significantly. Public blockchains like Universa utilize token-based models, which introduce a dynamic pricing mechanism. This could lead to fluctuating costs based on market demand. In contrast, specific project costs, as seen in the Observatory of Urban Mobility, provide a more stable but potentially higher upfront financial requirement. Understanding these subtle differences is crucial in assessing the economic feasibility and long-term sustainability of blockchain solutions in different sectors.

Blockchain technologies often promise enhanced efficiency and security compared to traditional systems. However, their cost-effectiveness is equally important. By comparing the costs associated with blockchain solutions to those of conventional technologies in similar application domains, one can determine the economic incentives or barriers to blockchain adoption. This comparison is vital in sectors where cost-saving is a primary driver for technology adoption.

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In blockchain solutions where tokenization is integral, such as DOVU, the economic implications are profound. The stability of token prices can affect the project's financial model, influencing stakeholder confidence and investment. Understanding the risks and rewards associated with token-based economies is essential for evaluating the overall cost-effectiveness of these solutions.

The benefits provided by blockchain technologies, such as enhanced transparency, security and efficiency, must be weighed against their costs. This cost-benefit analysis helps in determining the overall value proposition of each solution. For instance, if a technology offers significant improvements in data integrity but at a prohibitive cost, its practical utility may be limited.

The costs associated with blockchain technologies are not static. Factors like geographic location, scale of implementation and technological advancements play a crucial role in determining these costs. Future trends, such as the decreasing cost of technology and increasing efficiencies, could make blockchain solutions more accessible and affordable.

The affordability of blockchain solutions is a crucial factor in ensuring inclusivity. High costs can exclude smaller entities and marginalized communities from leveraging these technologies. Therefore, analyzing the cost in the context of financial accessibility is essential for promoting equitable technology adoption.

The cost of blockchain solutions also has implications for achieving SDGs. Expensive technologies may impede progress towards goals like affordable clean energy or sustainable cities. Conversely, cost-effective solutions can significantly contribute to these global objectives by enabling broader adoption and implementation.

Predicting future cost trends is vital for understanding the long-term economic viability of blockchain technologies. Factors influencing these trends include market adoption rates, technological improvements and changes in global economic conditions.

Finally, the cost structure of blockchain technologies influences funding and investment opportunities. Understanding the financial models behind these solutions can help investors and stakeholders make informed decisions, balancing risks with potential rewards.

In conclusion, the cost of blockchain technologies, as depicted in the provided dataset, is a multifaceted aspect that intersects with various other characteristics. Analyzing it in the context of type, application domain, benefits and other factors provides a comprehensive understanding of the economic and strategic implications of these technologies. This analysis is crucial for stakeholders, policymakers and investors in making informed decisions about adopting and investing in blockchain solutions.

#### 4.2.5. Application Domain (Sector)

The data collected for this paper reveals that blockchain technologies find applications across a wide array of sectors. This diversity reflects the versatility of blockchain as a technology. The sectors include:

1. **Economy, Safety, Transparency, Education, Health:** Solutions like “Universa” indicate a broad application in various critical sectors, underscoring blockchain's potential in enhancing economic processes, ensuring data safety, promoting transparency, contributing to educational platforms and improving healthcare systems.
2. **Sustainability and Ecology:** Technologies such as “Responsible Box” and “DOVU” focus on sustainability and ecological impacts. This suggests a growing trend in using blockchain to support environmental protection and sustainable development, highlighting its role in tracking carbon emissions, promoting eco-friendly initiatives and improving sustainable urban planning.

3. **Accessibility, Economy/Finance:** Solutions like “SmartKey” demonstrate the application of blockchain in enhancing accessibility and financial transactions. This signifies blockchain's role in creating more accessible economic frameworks and financial inclusivity.
4. **Public Transportation:** Applications in public transportation, as seen in the “Observatory of Urban Mobility”, indicate blockchain's utility in improving transit systems, enhancing operational efficiency and fostering sustainable urban mobility.

The varied application domains suggest an emerging trend of blockchain integration across multiple sectors. This indicates a move towards interconnected systems where blockchain acts as a bridge between different sectors, enhancing efficiency and collaboration. A significant focus on sustainability and ecology points towards blockchain's role in addressing global environmental challenges. This aligns with contemporary emphasis on sustainable development goals (SDGs) and indicates a future where blockchain could be pivotal in ecological conservation and sustainable practices. The application in sectors like health, education and public transportation suggests blockchain's potential in revolutionizing public services, making them more efficient, transparent and accessible. The presence in economic and financial sectors implies blockchain's transformative impact on the economy, potentially leading to more decentralized and inclusive financial systems.

The analysis of the "Application Domain (Sector)" column highlights blockchain technology's vast potential and adaptability across various crucial sectors. It underscores the technology's growing importance in shaping future economic, environmental and social frameworks. The diverse application domains suggest an evolving landscape where blockchain is not just a technological tool but a catalyst for intersectoral innovation and sustainable development.

#### 4.2.6. Level of Governance

In the evolving landscape of blockchain technology within the public sector, governance emerges as a critical factor shaping the efficiency and integrity of blockchain-based systems. This paper delineates the governance of blockchain in the public sector into three distinct levels: micro, meso and macro. Each level addresses unique aspects of governance, ranging from technical infrastructure to organizational dynamics and broader institutional frameworks.

##### **Micro Level Governance**

At the micro level, governance is primarily concerned with decisions referring to the technical infrastructure of blockchain-based systems. This includes the selection of blockchain architecture, either as permissionless or permissioned and public or private forms. Such decisions are instrumental in defining the operational dynamics and accessibility of the blockchain system. The architecture choice directly influences the blockchain's application architecture, predisposing it to specific functionalities and integrations.

Further, micro-level governance extends to ensuring interoperability, a crucial aspect for integrating blockchain systems with existing digital infrastructures. As highlighted in the European Interoperability Framework (EIF), effective governance at this level requires an integrated approach encompassing legal, technical, semantic and organizational interoperability. This facet is particularly relevant for entries in our dataset that demonstrate blockchain's integration in diverse public sector applications.

##### **Meso Level Governance**

Shifting focus to the meso level, governance here involves organizational processes and collective decision-making within blockchain networks. Key to this level is the decision-making mechanism, which can be either on-chain, involving direct stakeholder participation through the blockchain, or off-chain, through external governance structures. This distinction is crucial for understanding the governance dynamics in our dataset, as it influences how decisions are implemented and enforced in different blockchain applications.

Additionally, the incentive mechanism plays a pivotal role at the meso level, as exemplified by the Bitcoin model. Such mechanisms are vital for sustaining user engagement and contributing to the overall health of the blockchain network. The consensus mechanism, another cornerstone of

meso-level governance, coordinates decentralized actions and decision-making, ensuring the integrity and reliability of information added to the blockchain. The dataset entries reflect various consensus mechanisms, underlining their significance in public sector blockchain applications.

### **Macro Level Governance**

Finally, at the macro level, governance is contextualized within the broader institutional landscape. This involves the distribution of governance roles within the blockchain network, impacting how decisions are formulated and executed. The dataset reflects this in the diverse governance structures adopted across different applications. Additionally, accountability mechanisms, as per Treib et al.'s typology, regulate and enforce governance rules, including aspects like dispute resolution and change management. The macro-level governance thus shapes the overarching framework within which blockchain systems operate, influencing their alignment with public sector objectives and values.

### **Understanding the Essence of Governance Levels in BCT**

At the core of BCT governance lies the recognition that while all three levels of governance - micro, meso, and macro - are inherent to every blockchain system, the emphasis or focus on one over the others can vary significantly based on the specific decisions and strategic objectives of the blockchain initiative. This variance in focus does not imply that any level is absent or insignificant, rather it highlights where the primary governance efforts and challenges are being addressed at a particular point in time or within a specific context.

### **The Dynamic Interplay Among Governance Levels**

The interplay among the micro, meso, and macro levels of governance in BCT is dynamic and continuous. Each level of governance not only addresses distinct aspects of governance but also interacts with and influences the others. For instance, technical decisions at the micro level (such as the choice of a consensus mechanism) can have implications for organizational processes at the meso level (affecting how decisions are made or how incentives are structured) and can also impact macro-level considerations (in terms of regulatory compliance or alignment with public sector objectives).

In conclusion, while all BCTs inherently engage with micro, meso, and macro levels of governance, the focal point of their governance efforts can differ, reflecting the unique challenges, priorities, and strategic objectives of each blockchain project. Understanding this detailed governance landscape is essential for appreciating the complexity of BCT and its potential to innovate and transform public sector operations and beyond. This perspective highlights the importance of a holistic approach to blockchain governance, one that recognizes the interdependencies among the technical, organizational, and institutional dimensions of blockchain initiatives.

This structured analysis provides a comprehensive understanding of blockchain governance, as reflected in the dataset. By examining governance across these three levels, we gain insights into the complex nature of BCTs, revealing how technical, organizational and institutional factors coalesce to shape their development and implementation.

### **Understanding the categorization of the dataset**

In the dataset explored in this paper, the research methodically categorizes blockchain technologies (BCTs) based on the primary level of governance they emphasize. While acknowledging that all levels of governance - micro, meso, and macro - are integral to the functioning of any BCT, the analysis aims to pinpoint where each blockchain's governance efforts predominantly lie. This approach illustrates that, although every BCT navigates governance concerns across all three levels, they tend to prioritize one level based on their specific goals, challenges, and operational contexts. This categorization sheds light on the diverse strategies and focuses within the blockchain landscape, revealing how different projects allocate their governance efforts to best meet their objectives and address the unique demands of their applications.

#### 4.2.7. Types of Decisions

##### **Types of Governance Decisions in Blockchain Applications in the Public Sector**

Building on the earlier discussion of the three levels of blockchain governance in the public sector, it's crucial to delve into the specific types of decisions that define and drive these levels. These decisions, as identified in our dataset, range across the micro, meso and macro levels, each playing a pivotal role in shaping the efficacy and alignment of blockchain technologies with public administration objectives.

##### **Micro-Level Decisions**

At the micro level, where the focus is on the technical infrastructure of the blockchain system, critical decisions include:

- **Infrastructure Architecture:** Choices between permissionless or permissioned, public or private blockchains set the foundational structure and access controls of the system.
- **Application Architecture:** This involves designing blockchain applications to fulfill specific public sector functionalities.
- **Interoperability:** Key for integrating blockchain systems with existing digital infrastructures, ensuring seamless data exchange and operational compatibility.

##### **Meso-Level Decisions**

Moving to the meso level, which centers on organizational processes within blockchain networks, key decisions are:

- **Decision-Making Mechanism:** This pertains to the processes, either on-chain or off-chain, through which decisions within the blockchain network are made.
- **Incentive Mechanism:** Strategies to motivate network participation, vital for maintaining an active and engaged user base.
- **Consensus Mechanism:** Central to the blockchain's operation, these decisions determine how network consensus is achieved for validating transactions and adding new blocks.

##### **Macro-Level Decisions**

At the macro level, which involves the broader institutional context, decisions are focused on governance structures and accountability mechanisms:

- **Organization of Governance:** Decisions here relate to the distribution of governance roles within the blockchain network, impacting how governance is conducted.
- **Accountability of Governance:** These decisions involve establishing frameworks for regulating and enforcing governance rules.
- **Control of Governance:** This includes the mechanisms for implementing governance decisions, balancing automation with human oversight.

In conclusion, these decision types, as categorized in our dataset, offer a comprehensive view of governance in blockchain applications within the public sector. They illustrate how technical, organizational and institutional decisions interplay to shape blockchain systems, ultimately affecting their success and alignment with public sector values and goals.

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##### **Interconnection Between Levels of Governance and Types of Decisions in Blockchain Applications**

The governance of blockchain technology, when viewed through the lens of its various applications, reveals a complex relationship between different levels of governance and the types of decisions that define them. This interplay is critical in determining how blockchain systems are designed, implemented and managed.

##### **Micro-Level Interconnections**

At the micro level, the focus is on technical decisions regarding the blockchain's infrastructure and application architecture, as well as its interoperability capabilities. These decisions, such as choosing between a permissioned or permissionless blockchain, directly influence the system's operational dynamics and user access. Decisions around application architecture are pivotal in determining the blockchain's functional capabilities and suitability for different applications. Similarly, interoperability decisions are essential for ensuring that blockchain systems can seamlessly integrate and communicate with existing and emerging digital ecosystems.

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In conclusion, the relationship between the levels of governance and types of decisions in blockchain applications is integral to the technology's success. This interconnectedness ensures that blockchain systems are not only technically sound but also aligned with the organizational and institutional realities of their application environments. Understanding this dynamic is key to developing blockchain solutions that are effective, adaptable and responsive to the diverse needs of various applications.

### **4.2.8. Benefits**

In exploring the landscape of blockchain technologies, the "Benefits" column of the provided dataset reveals a diverse and multifaceted range of advantages, each unique to the specific blockchain application. These benefits not only demonstrate technical proficiency but also align significantly with broader societal and global objectives, as evidenced by their connection to the United Nations Sustainable Development Goals (SDGs). This connection to the United Nations Sustainable Development Goals (SDGs) is significant in the context of this research, as reflected by the dedicated column for SDGs in the dataset and will be further analyzed in a later section of the paper.

A prominent aspect across various blockchain solutions is the emphasis on efficiency gains. This relates to the facilitation of faster and more efficient transactions, as well as to improvements in data management and operational processes. Such enhancements are crucial in scenarios where expedited and reliable processes are essential. Moreover, these efficiency improvements often correlate with SDG targets like industry innovation and infrastructure development, underlining their relevance in achieving global development objectives.

Enhanced citizen engagement is another significant benefit observed in the dataset. Blockchain's inherent qualities of transparency and reliability are key in applications focused on public service and governance. This fosters a sense of trust and active participation among citizens, aligning with SDGs that emphasize sustainable cities, communities and responsible institutions.

Environmental sustainability is a standout focus for some blockchain solutions, showcasing technology's role in promoting eco-friendly practices. This is particularly pertinent in the context of SDGs related to sustainable cities, climate action and life on land. Blockchain's capability to contribute to environmental conservation efforts is a testament to its potential in supporting global ecological sustainability goals.

The scalability and adaptability, denoted by 'Easy Replication', of certain blockchain technologies indicate their potential for widespread application. This adaptability is crucial for meeting various SDG targets, as it allows for solutions to be tailored and implemented in diverse global contexts, from developed urban settings to rural areas in developing countries.

Specific technologies like Universa highlight a broad spectrum of benefits including efficiency gains, citizen engagement and environmental sustainability, indicating their alignment with multiple SDGs. Solutions such as DOVU, with its focus on urban mobility and ecological sustainability,

demonstrate how blockchain can address specific sectoral challenges while contributing to relevant SDG targets.

In summary, the benefits of blockchain technologies, as outlined in the dataset, extend beyond mere technical improvements. They resonate with key global priorities and are intricately linked with the SDGs. This connection is vital, as it positions blockchain not just as a technological innovation but as a tool capable of contributing to the achievement of global development goals. The specific benefits associated with each blockchain technology in the dataset illustrate its capacity to address a wide array of challenges, reaffirming blockchain's role as a versatile and impactful tool in the contemporary technological and global development landscape.

#### 4.2.9. Problems Addressed

Blockchain technology, renowned for its decentralization, transparency and security, addresses a myriad of problems across diverse sectors. Each application of blockchain is tailored to tackle specific challenges, reflecting its versatility and adaptability.

“Universa”, for instance, exemplifies blockchain's transformative impact on the economic and social fabric of nations. By leveraging blockchain's robust infrastructure, “Universa” aims to streamline financial transactions and social interactions, enhancing efficiency and trust in these domains. [14]

The “Responsible Box” project highlights blockchain's role in goal-oriented initiatives. This application underscores blockchain's capability to bring transparency and accountability to processes, ensuring objectives are met with integrity and reliability. [15]

Urban mobility and traffic congestion, a common plight in metropolitan areas, also find a remedy through blockchain applications. By integrating blockchain technology, solutions can be developed to optimize traffic flow, reduce congestion and improve overall urban transport systems, demonstrating blockchain's potential in urban planning and development.

Furthermore, blockchain's reach extends to organizational structures. Many blockchain solutions are developed by companies specifically to address internal inefficiencies and to foster more streamlined, transparent operations. This internal application showcases blockchain's capacity to enhance operational effectiveness within corporate environments

Lastly, the case of Mobility in Teresina illustrates blockchain's utility in addressing urban challenges. The technology plays a pivotal role in overcoming hindrances in urban mobility, signifying its potential in enhancing quality of life in densely populated areas. [18]

In summary, the “Problems Addressed” by blockchain technology, depicted in the data with their own column, are diverse and far-reaching, demonstrating its potential as a versatile and powerful tool for tackling a wide array of challenges in modern society.

#### 4.2.10. SDG Connection

The intersection of blockchain technology with the United Nations “Sustainable Development Goals (SDGs)” underscores its potential to contribute significantly to global sustainable development. Each blockchain application aligns with specific SDGs, showcasing the technology's role in advancing these global objectives. Blockchain initiatives that contribute to SDG 4: Quality Education and SDG 7: Affordable and Clean Energy illustrate the technology's capability in enhancing educational access and promoting sustainable energy solutions. Projects focusing on SDG 11: Sustainable Cities and Communities and SDG 12: Responsible Consumption and Production aim to improve urban life quality and encourage environmentally friendly consumption patterns. Additionally, the overlap with SDG 3: Good Health and Well-being demonstrates blockchain's potential in healthcare systems.

Further detailed connections of blockchain with each SDG are as follows:

- SDG 1: No Poverty - Blockchain enhances financial inclusion, aiding poverty alleviation.
- SDG 2: Zero Hunger - Improves food supply chain transparency, addressing global hunger.
- SDG 3: Good Health and Well-being - Revolutionizes healthcare data management and efficiency.

- SDG 4: Quality Education - Secures and streamlines academic credential verification and
- SDG 5: Gender Equality - Provides equitable access to financial and digital resources for women and girls.
- SDG 6: Clean Water and Sanitation - Manages water resources efficiently, improving services.
- SDG 7: Affordable and Clean Energy - Facilitates sustainable energy management and peer-to-peer energy trading.
- SDG 8: Decent Work and Economic Growth - Creates tech sector jobs and fosters financial inclusion.
- SDG 9: Industry, Innovation and Infrastructure - Advances sustainable industrialization and infrastructure development.
- SDG 10: Reduced Inequalities - Offers decentralized access to financial services, reducing economic disparities.
- SDG 11: Sustainable Cities and Communities - Enhances urban planning, resource allocation and sustainable community development.
- SDG 12: Responsible Consumption and Production - Ensures ethical product sourcing and reduces environmental footprints.
- SDG 13: Climate Action - Contributes to tracking carbon emissions and promoting sustainable environmental practices.
- SDG 14: Life Below Water - Aids in sustainable fishing practices and marine biodiversity conservation.
- SDG 15: Life on Land - Supports wildlife conservation and transparent funding for conservation initiatives.
- SDG 16: Peace, Justice and Strong Institutions - Aids in corruption prevention and promotes legal frameworks.
- SDG 17: Partnerships for the Goals - Facilitates secure and transparent international collaborations.

In conclusion, the "SDG Connection" of blockchain technology not only highlights its technological capabilities but also its capacity to drive sustainable and inclusive growth across various critical global challenges. [60] [61]

#### 4.2.11. Countries

The adoption and consideration of blockchain technology by governments worldwide, as well as its application in global contexts, reflect its growing importance in both national and international spheres.

- BRICS (Brazil, Russia, India, China and South Africa): These emerging national economies are exploring blockchain to enhance intergovernmental cooperation, improve public services and foster economic growth, with initiatives ranging from financial systems improvements to governmental transparency enhancements.
- Italy: Italy is integrating blockchain into public sectors, focusing on security, efficiency, digital identity and record-keeping systems.
- United Kingdom: The UK emphasizes blockchain in public sector innovation, exploring its potential in healthcare, taxation and governmental process streamlining.
- Poland: Poland considers blockchain for revolutionizing public services, including document authentication, public record management and governmental operation transparency.
- Brazil: Brazil focuses on using blockchain to improve public administration efficiency and transparency, with applications in public record keeping and government data security.

In addition to these national applications, blockchain's role in global governance is increasingly recognized. Blockchain technology offers unique advantages for international cooperation:

- Cross-Border Collaboration: Blockchain facilitates secure and transparent cross-border transactions, enabling smoother international trade and cooperation. Its decentralized nature allows for efficient collaboration without the need for intermediaries.

- **Global Standards and Regulations:** The global nature of blockchain technology necessitates the development of international standards and regulations. This fosters collaboration among nations to create harmonized blockchain frameworks, ensuring security, interoperability and legal compliance across borders.
- **International Projects and Initiatives:** Blockchain is instrumental in international projects focusing on global challenges like climate change, humanitarian aid and international finance. For instance, blockchain-based platforms can ensure transparent and efficient distribution of resources in international aid programs.
- **United Nations Involvement:** The United Nations and its agencies are exploring blockchain applications for achieving Sustainable Development Goals (SDGs), highlighting the technology's potential in global governance and development.

In conclusion, the engagement of various governments with blockchain technology, along with its increasing role in global governance, demonstrates the technology's versatility and potential to transform both national public administration and international cooperation. It paves the way for more efficient, transparent and secure operations at both the governmental and global levels.

#### 4.2.12. Application Level

The application level of blockchain technology encompasses a diverse range, including municipal, regional, organizational, enterprise, community, international and global levels. This variety demonstrates blockchain's adaptability across various scales and types of governance and administration.

- **Municipal Level:** At this level, blockchain addresses local governance issues, enhances city services and improves citizen engagement through smart city initiatives, identity verification and municipal record keeping.
- **Regional Level:** Blockchain applications at the regional level focus on broader issues like inter-city transportation coordination and public service delivery, promoting regional cooperation and resource allocation efficiency.
- **Organizational Level:** Within organizations, blockchain enhances internal processes, data management and operational efficiency, supporting tasks like record-keeping, workflow automation and transparency enhancement.
- **Enterprise Level:** For enterprises, blockchain is crucial in managing business-to-business interactions and secure corporate transactions, offering solutions for logistics, finance and other complex enterprise needs.
- **Community Level:** At the community level, blockchain supports decentralized solutions empowering local communities and community resource management.
- **International Level:** Blockchain at the international level facilitates cross-national collaboration, enhancing secure and efficient interactions between nations. It plays a key role in international trade facilitation, diplomatic communication and cross-border regulatory compliance.
- **Global Level:** On a global scale, blockchain is instrumental in worldwide initiatives, transcending national boundaries. It supports international financial transactions fostering secure and efficient global operations.

In conclusion, the varied application levels of blockchain technology—from local to global—illustrate its versatility and potential in revolutionizing governance and service delivery. Each level presents unique blockchain applications, reflecting specific needs and challenges and showcasing its transformative potential across different contexts and scales.

#### 4.2.13. Types of solutions

In this paper, a crucial distinction within Blockchain Technology Solutions (BCTs) is emphasized: the separation into applications and infrastructure. This categorization is essential for a clear and organized understanding of blockchain technology's extensive capabilities. Applications are the practical use cases of blockchain, leveraging its core features such as immutability, transparency,

and decentralization to create innovative solutions for various industries. Infrastructure, on the other hand, refers to the essential components and systems that allow these applications to function effectively, including the underlying protocols, networks, and frameworks. This division not only simplifies the complex landscape of blockchain technology but also highlights the interdependence between the practical uses of blockchain and the technical foundation that enables them. Throughout this paper, our exploration into the applications and infrastructure of blockchain aims to broaden our understanding of how each contributes to different sectors, revealing the comprehensive yet intricate structure that supports this transformative technology.

### **Applications: User-Focused Solutions**

Blockchain applications represent the end-user services and solutions that leverage the underlying blockchain infrastructure to deliver specific functionalities. These applications are essentially the interface through which users interact with the blockchain technology, benefiting from its unique features such as decentralization, immutability, and transparency. Examples of blockchain applications span a wide range, including but not limited to:

- **Cryptocurrencies and Digital Payments:** Such as Bitcoin and Ethereum, which facilitate secure, peer-to-peer transactions without the need for intermediaries, revolutionizing the financial sector.
- **Smart Contracts:** Automated contracts that execute predefined conditions, enhancing efficiency and trust in transactions across various domains like real estate, legal agreements, and supply chain management.
- **Decentralized Applications (dApps):** These operate on a blockchain or peer-to-peer network of computers instead of a single computer, offering a wide range of services from decentralized finance (DeFi) platforms to social media applications, all benefiting from the increased security and reduced risk of censorship.
- **Digital Identity and Verification Services:** Providing a secure and immutable way to verify identities and credentials, crucial for sectors such as banking, education, and healthcare.

### **Infrastructure: The Backbone of Blockchain**

Blockchain infrastructure, on the other hand, encompasses the foundational technological layers that enable the operation and existence of blockchain applications. This includes:

- **The Core Blockchain Protocol:** Determines how the blockchain operates, including its consensus mechanism (such as Proof of Work or Proof of Stake), which ensures all participants in the network agree on the valid state of the blockchain ledger.
- **Network Infrastructure:** The hardware and software that form the network's backbone, allowing for the creation, transmission, and storage of blocks.
- **Development Tools and Platforms:** Necessary for creating blockchain applications, including frameworks and interfaces for smart contracts and dApps development.
- **Security Mechanisms:** Ensuring the integrity and security of transactions and data on the blockchain.

The relationship between blockchain applications and infrastructure is inherently symbiotic. Applications rely on a robust, secure, and efficient infrastructure to function and deliver their intended benefits, such as enhanced transparency, security, and efficiency. Conversely, the development and proliferation of innovative and useful applications can drive the growth and adoption of blockchain technology, encouraging further investment in and development of the underlying infrastructure. Together, they form the comprehensive landscape of blockchain technology, with each playing a pivotal role in realizing the technology's full potential across various sectors.

### **How to differentiate between the two**

To differentiate between a BCT as an application or infrastructure, one can look at its intended use and functionality. If a solution directly interacts with end-users or provides a specific service leveraging blockchain technology, such as a platform for executing smart contracts or a system for

tracking the provenance of goods, it falls into the category of applications. These are built on top of the blockchain and are designed with the user experience in mind, focusing on solving practical problems or enhancing certain aspects of business or personal transactions.

Conversely, if a solution pertains to the underlying mechanisms that allow these user-focused platforms to operate, such as the development of a new consensus algorithm, enhancements to blockchain scalability, or security protocols, it is considered part of the blockchain infrastructure. These solutions are more concerned with the technical capabilities and efficiency of the blockchain itself, aiming to improve the foundational elements that support applications.

Understanding this distinction is vital for developers, since it guides where to focus their efforts, whether in creating innovative applications that address industry-specific challenges or in enhancing the blockchain infrastructure to support a broader range of applications more effectively. For businesses and end-users, recognizing the difference helps in selecting the right type of blockchain solution that meets their specific needs, whether they require a direct blockchain application to improve their operations or services or need to invest in the infrastructure to support their long-term blockchain strategy.

In summary, differentiating between applications and infrastructure in BCTs hinges on examining the purpose and functionality of the solution, whether it addresses end-user needs directly through blockchain-based services or improves the technical foundation that enables those services.

## 5. Results

### 5.1. The BCT solutions

- |                                           |                                     |
|-------------------------------------------|-------------------------------------|
| 1. Universa [14]                          | 23. NEO [36]                        |
| 2. Responsible Box [15]                   | 24. Algorand [37]                   |
| 3. DOVU [16]                              | 25. VeChain [38]                    |
| 4. SmartKey [17]                          | 26. Ardor [39]                      |
| 5. Observatory of Urban Mobility [18]     | 27. Stellar [40]                    |
| 6. Personal Health Record OS (phrOS) [19] | 28. IOTA [41]                       |
| 7. IoMob [20]                             | 29. Chainlink [42]                  |
| 8. XignIn City [21]                       | 30. Polkadot [43]                   |
| 9. Changers CO2 Fit App [22]              | 31. Avalanche [44]                  |
| 10. DataBroker DAO [23]                   | 32. Solana [45]                     |
| 11. Smart City Database Platform [24]     | 33. Corda [46]                      |
| 12. GlobalTech.City [25]                  | 34. Zilliqa [47]                    |
| 13. Vizsafe [26]                          | 35. Cardano [48]                    |
| 14. DECODE [27]                           | 36. Cosmos [49]                     |
| 15. Councilbox OVAC [28]                  | 37. Elrond [50]                     |
| 16. SDG Assessment App [29]               | 38. Qtum [51]                       |
| 17. Hedera [30]                           | 39. NEM (New Economy Movement) [52] |
| 18. Hyperledger Fabric [31]               | 40. Ontology [53]                   |
| 19. Corda by R3 [32]                      | 41. Waves [54]                      |
| 20. Quorum [33]                           | 42. Aeternity [55]                  |
| 21. EOS.IO [34]                           | 43. Icon (ICX) [56]                 |
| 22. Tezos [35]                            | 44. Holochain [57]                  |
|                                           | 45. Harmony (ONE) [58]              |
|                                           | 46. Lisk [59]                       |

## 5.2. Description of solutions

1. Smart platform based on Blockchain technology will create forms of relationships between people, city services and business in various areas of life in the region, reducing financial expenses.
2. This part of the research project aim to develop a social approach that can be used in each city during events in order to implement a more sustainable behavior and transparency. The Responsible Box is a plug and play system that can be installed in several areas all around the World.
3. A blockchain-based crypto-token (DOV), that can be used as a reward within the transportation and mobility sector. An ecosystem, where once you earn the token, you can redeem it and use it within the ecosystem.
4. The young, but powerful crypto asset market is almost entirely virtual. With smartkey, the crypto asset world gains access to the entire economy, based on the distribution of access to physical objects such as hotels, cars or parking spaces. The ability of creating smart contracts on the blockchain we gain access to an innovative economy which is ready to be used in real smart products that surround us. The SmartKey ecosystem plays the role of a marketplace for the services of the blockchain economy such as decentralised finance, loans, insurance and the whole of the DeFi sector.
5. Teresina will receive technical and financial support to foster mitigation and adaption actions. The project involves the use of blockchain technology to improve the public transportation system of Teresina.
6. Personal Health Record OS (phrOS) is a blockchain based platform for the healthcare industry. It allows healthcare providers & patients to access their secured medical record seamlessly.
7. IoMob is building an open mobility ecosystem model whereby users will be able to have immediate access to all legal mobility services available in their city. Furthermore intermodal public and private options will be available as will closed/private Mobility as a Service (MaaS) models and something we refer to as dMaaS (decentralized MaaS) whereby users can have customized MaaS mobility aggregation services.
8. XignSys wants to establish secure and usable Citizen Identities. To achieve this, a technology has been developed that uses only the smartphone for login processes - but without transferring sensitive data to third parties.
9. With Changers we enable cities to create their own climate currency and teach their citizens about the possibilities to reduce their effect on the climate. Users and City can monitor their individual CO2 balance and the over all achievements. Competing with each other, planting trees, taking part in raffles or redeeming coins makes the system playful and sticky.
10. Today companies make use of sensor data to optimize and monitor their operations. The result is a single purpose data landscape. DataBroker DAO drives the evolution towards truly 'smart living' by making this data easily accessible to cities, organizations and entrepreneurs at an affordable price. Smart City initiatives can limit the upfront cost of populating the town with sufficient sensors and turn the expense into an investment with a 2-3 year payback period and a continuous income stream after that.
11. By connecting all sensors and actors and by providing existing solutions and incentive to participate we managed to create a platform to facilitate smart city application development. The platform has no limitations regarding sensor type and can handle all types of real-time data.
12. GlobalTech.City connects the AmsterdamTech.City to other cities around the world.
13. The mission of Vizsafe is to empower every person to participate in the safety of the communities where they live, work, visit and play, doing well by doing good(TM)
14. DECODE is a project to develop tools to manage personal information on the internet.

15. We have implemented a solution that allows them to carry out procedures without having to travel to the administration, generating a very positive impact on the carbon footprint and with a very high return on investment.
16. A smart cities solution to help urban businesses and communities meet sustainability challenges utilizing digital technology to measure, report and verify ESG performance aligned to UN SDGs.
17. Verifiable time-stamping and ordering of events for any web2 or web3 application.
18. An open-source enterprise-grade permissioned distributed ledger technology (DLT) platform, designed for use in enterprise contexts, providing a foundation for developing applications with a modular architecture.
19. A blockchain platform designed specifically for businesses, enabling the direct and private exchange of value using smart contracts.
20. An open-source blockchain platform, a fork of Ethereum, designed for enterprise use with high speed and privacy.
21. EOS.IO is a blockchain protocol focused on commercial-scale decentralized applications (dApps), known for its high transaction speeds and scalability. Developed by Block.one, it aims to solve issues related to dApp operation on blockchain.
22. Tezos is an open-source, decentralized blockchain known for its self-upgradability and a unique governance system. It supports peer-to-peer transactions and smart contract deployment.
23. NEO, originally named Antshares, is a blockchain-based platform for running smart contracts and decentralized applications. It focuses on digitizing assets and automating the management of digital assets using smart contracts, aiming to create a smart economy.
24. Algorand is a decentralized, scalable and secure blockchain infrastructure, focusing on improving scalability without sacrificing decentralization. It uses a Pure Proof of Stake (PPoS) consensus mechanism and supports smart contracts and DApps.
25. VeChain, founded in 2015, is a blockchain platform designed to enhance supply chain management and business processes. It utilizes IoT applications for supply chain management and has a dual-token setup: VeChain Token (VET) and VeChainThor Energy (VTHO).
26. Ardor is a multi-chain blockchain-as-a-service (BaaS) platform, evolved from NXT, featuring a unique parent-child chain architecture for scalability, customization and increased throughput. It addresses blockchain bloat, scalability issues and customization challenges by separating the network security chain (main chain) from transactional chains (child chains), where each child chain operates independently with its own tokens, while the Ardor main chain ensures security and decentralization.
27. Stellar is a decentralized, public blockchain founded in 2014, optimized for payments and enabling cross-border transactions, tokenization of assets and making financial services accessible and affordable. It is an open network for storing and moving money, allowing users to create, send and trade digital representations of all forms of money—dollars, pesos, bitcoin, etc. Its main goal is to unite the world's financial infrastructure, ensuring money can flow quickly and cheaply between banks, businesses and people.
28. IOTA is an open-source distributed ledger specifically designed for the Internet of Things (IoT) ecosystem, focusing on recording and executing transactions between machines and devices. It employs a unique system called the Tangle, a Directed Acyclic Graph (DAG) that differs from traditional blockchain architecture, enabling high scalability and zero-fee transactions for both data and value transfer. This architecture allows for a system of nodes that confirms transactions, emphasizing efficiency and scalability within the IoT space.
29. Chainlink is a decentralized oracle network that connects real-world data to smart contracts on blockchain platforms. It enables secure and reliable off-chain computation and data access, expanding the utility of smart contracts.
30. Polkadot is a multi-chain application environment that enables cross-chain interoperability on a level previously not possible. It allows diverse blockchains to transfer messages in a trust-free fashion, sharing their unique features while pooling their security.

31. Avalanche is a highly scalable blockchain platform for decentralized applications and custom blockchain networks. It is known for its high throughput, low latency and resistance to 51% attacks. It aims to address the blockchain trilemma: achieving scalability, security and decentralization simultaneously.
32. Solana is a high-performance blockchain supporting builders around the world creating crypto apps that scale today. It is recognized for its high throughput and low transaction costs, aiming to solve the scalability issues without sacrificing decentralization.
33. Corda is an open-source blockchain platform designed specifically for businesses. It enables companies to transact directly and in strict privacy using smart contracts, reducing transaction and record-keeping costs and streamlining business operations.
34. Zilliqa is a high-performance, high-security blockchain platform for enterprises and next-generation applications. It introduced sharding to blockchain, dividing the network into several smaller component networks capable of processing transactions in parallel.
35. Cardano is a blockchain platform for changemakers, innovators and visionaries, offering tools and technologies required to create possibility for the many, as well as the few and bring about positive global change. It is the first blockchain platform to be built through peer-reviewed research.
36. Cosmos is a decentralized network of independent parallel blockchains, each powered by BFT consensus algorithms like Tendermint. It's known as the "Internet of Blockchains," aiming to create an ecosystem of blockchains that can interoperate and scale together.
37. Elrond is a highly scalable, fast and secure blockchain platform for distributed apps, enterprise use cases and the new internet economy. It aims to provide extremely high network speeds and low transaction costs, using sharding to achieve scalability.
38. Qtum is an open-sourced blockchain application platform. Qtum combines the security of UTXO model from Bitcoin with the flexibility of smart contract execution from Ethereum. It aims to bring the best of both worlds to foster business-oriented use cases.
39. NEM is a blockchain platform that offers an efficient way to manage assets and data easily and at a low cost. It is designed with modularity and customizable features, making it suitable for a variety of enterprise solutions, including supply chain, finance and notarization.
40. Ontology is a high-performance public blockchain and distributed collaboration platform. It specializes in digital identity and data, aiming to provide a decentralized trust ecosystem. Ontology's unique infrastructure supports layer 2 scalability and robust cross-chain collaboration.
41. Waves is a multi-purpose blockchain platform supporting a variety of use cases including decentralized applications (DApps) and smart contracts. Known for its user-friendly approach, Waves enables users to create and launch custom cryptocurrency tokens without extensive smart contract programming.
42. Aeternity is a blockchain platform that emphasizes scalable smart contracts interfacing with real-world data. It offers unique features like state channels for off-chain scaling and oracles for incorporating real-world data into blockchain-based applications.
43. Icon aims to build one of the world's largest decentralized networks, allowing various blockchains to interact with each other via smart contracts. It's designed to function as a framework for interconnected blockchain networks, facilitating hyperconnectivity.
44. Holochain is a post-blockchain technology that offers a framework for designing and running distributed applications. It is unique in that it does not require global consensus to operate, making it more efficient and scalable than traditional blockchain technology. Holochain is designed for peer-to-peer collaboration without the energy consumption and scalability issues of conventional blockchains.
45. Harmony is a fast and open blockchain for decentralized applications. Its main focus is on scalability and decentralization, aiming to provide a high-throughput, low-latency and low-fee consensus platform. Harmony employs sharding to increase network capacity and transaction speed.
46. Lisk is a blockchain application platform that enables developers to build blockchain applications in JavaScript. It aims to make blockchain technology more accessible with its

sidechain development kit (SDK). Lisk focuses on user experience and developer support, emphasizing the importance of accessible blockchain technology.

### 5.3. Identified benefits and problems addressed

Table 2: Benefits & Problems addressed

| # | <u>Benefits</u>                                                                                                          | <u>Problems addressed</u>                                                                                                                                                                                                                                                                                                                                                                     |
|---|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Connectivity, Cost Savings, Inclusion and Equality | Universa transforms the economic and social life of the region to a brand new digital level                                                                                                                                                                                                                                                                                                   |
| 2 | Easy Replication, Environmental Impact                                                                                   | The preliminary goal of the responsible box is real time monitoring of the energy flows in a big concert area (Carroponete),<br><br>in order to predict the power consumption based on the clustering of all possible events (machine learning).                                                                                                                                              |
| 3 | Easy mobility, easy parking, sustainable transportation, controlled traffic flow, reduced pollution                      | In urban areas, we all get stuck in traffic; we all live amongst pollution, which partially is caused by the vehicles we drive; we use products not very wisely, which leads to excessive waste.                                                                                                                                                                                              |
| 4 | Easy Replication, Life Quality, Connectivity, Cost Savings                                                               | Most blockchain solutions are built by companies and corporations, which means that they do not allow the exchange of data or users, which stands in the way of mass adoption and benefits large corporations in the fight for users.                                                                                                                                                         |
| 5 | Efficiency Gains, Citizen Engagement, Connectivity, Environmental Impact                                                 | Mobility in Teresina has been hindered by urban sprawl.<br><br>The horizontal growth directly impacts in public transport: increased distances per trip and reduced fluidity, traffic safety, reduced efficiency, efficacy (obtaining desirable results) and effectiveness (guarantee of continuity),<br><br>increasing its cost of implementation, maintenance and compromising its quality. |
| 6 | Easy Replication, Cost Savings                                                                                           | High administrative costs, lack of true interoperability between various EHRs, limited accessibility to one's own healthcare records, medical data stored in hospital silos; vulnerable to data breaches,<br><br>lack of trust, uniformity and data integrity, hurting big data analytics                                                                                                     |

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|    |                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                |
|----|-----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7  | Smart mobility                                                                                                                                | Fragmented mix of public and private mobility services creating inefficiency in mobility service delivery and barriers to scalable innovation.                                                                                                                                                                                 |
| 8  | Efficiency Gains, Life Quality, Cost Savings, Inclusion and Equality, Interoperability                                                        | XignIn City is the authentication solution for digital identities, which is used by citizens to communicate with their municipality, governmental organisations and businesses that provide smart city solutions.<br>In smart city the XignIn City app acts as a platform to provide services like mobility products and more. |
| 9  | Citizen Engagement, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality                 | Motivates citizens to walk more often, cycle, use public transport and take part in environment friendly and sustainable activities, where they learn more about waste reduction, healthy nutrition, energy saving and much more.                                                                                              |
| 10 | Efficiency Gains, Life Quality, Connectivity, Environmental Impact                                                                            | Expensive acquisition and maintenance of IoT sensors.                                                                                                                                                                                                                                                                          |
| 11 | Easy Replication, Efficiency Gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality | How to connect all sensors and actors with each other.                                                                                                                                                                                                                                                                         |
| 12 | Efficiency Gains, Connectivity                                                                                                                | The city events of Amsterdam are also a valuable source of knowledge and information to other places. To accomplish that a network of smart cities is creating where a vivid exchange of knowledge is possible.                                                                                                                |
| 13 | Citizen Engagement, Life Quality, Connectivity, Knowledge Sharing, Inclusion and Equality                                                     | Citizens, as the primary users of urban infrastructure, are an untapped resource for reporting issues due to the absence of suitable reporting platforms and immediate incentives.                                                                                                                                             |
| 14 | Connectivity                                                                                                                                  | DECODE is a project to develop tools to manage personal information on the internet.                                                                                                                                                                                                                                           |
| 15 | Easy Replication, Citizen Engagement, Life Quality, Cost Savings, Environmental Impact, Inclusion and Equality                                | The citizen needs to carry out procedures with the public administration, sometimes we can find ourselves with complex procedures that need the help of qualified staff.<br>We need to travel to the entity with the cost of fuel and parking, which means a considerable amount of money and time.                            |

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|    |                                                                                                                                                     |                                                                                                                                                                                                                              |
|----|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 16 | Efficiency Gains, Citizen Engagement, Connectivity, Cost Savings, Environmental Impact, Inclusion and Equality                                      | Cities account for 60% of global carbon emissions. 2/3 of businesses have no plan for sustainability. Business engagement is necessary to achieve net zero emissions and UN SDGs                                             |
| 17 | Fast, fair and secure transactions, privacy and scalability, low cost of operating private networks                                                 | digitalization, transactions, immune transactions                                                                                                                                                                            |
| 18 | Efficiency Gains, Scalability, Trust, Privacy, Confidentiality, Citizen Engagement, Life Quality                                                    | Improves transparency and trust in multi-party systems. Provides a platform for building enterprise-grade blockchain networks with high scalability and transaction rates.                                                   |
| 19 | Efficiency Gains, Regulatory Compliance                                                                                                             | Streamlines business transactions, reduces redundancy and ensures data integrity.                                                                                                                                            |
| 20 | Privacy, Scalability, Interoperability                                                                                                              | Provides high performance and privacy for enterprise applications.                                                                                                                                                           |
| 21 | Scalability, Speed, Low Transaction Costs, Developer-friendly                                                                                       | Addresses scalability and speed issues for dApps, offers a flexible and powerful platform for dApp development.                                                                                                              |
| 22 | Self-upgradability, Security, Governance model, Developer-friendly                                                                                  | Addresses key barriers in blockchain adoption for assets and applications, focuses on evolution and adaptability.                                                                                                            |
| 23 | Smart Economy, Digital Identity, Asset Digitization, Scalability                                                                                    | Focuses on digital asset management and automating smart contracts for a distributed network.                                                                                                                                |
| 24 | High scalability, Security, Low transaction costs                                                                                                   | Focuses on solving scalability issues while maintaining decentralization and security in blockchain technology.                                                                                                              |
| 25 | Supply Chain Optimization, IoT Integration, Transparency, Low Carbon Footprint                                                                      | Streamlines complex supply chain processes and information flow using blockchain and IoT.                                                                                                                                    |
| 26 | Scalability, Customization, BaaS platform, Innovation in multi-blockchain platforms, Reduced Blockchain Bloat, Energy Efficiency, Enhanced Security | Addresses the need for scalable and customizable blockchain solutions for businesses and organizations, blockchain scalability and bloat, customization limitations in existing blockchain platforms, energy efficiency.     |
| 27 | High-speed transactions, Low costs, Energy efficiency, Accessible financial services                                                                | Reduces cost and complexity of international transfers, addresses high costs and slow processing times of cross-border payments, tackles lack of financial inclusion, targets inefficiencies in traditional banking systems. |

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|    |                                                                                                                                           |                                                                                                                                                                                                                               |
|----|-------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 28 | Scalability, No transaction fees, Data Integrity, Designed for IoT, Energy efficient, Decentralized and Autonomous Operations             | Scalability and high resource requirements in IoT ecosystems, eliminates transaction fees for more efficient operations, ensures data security and integrity, provides a lightweight and efficient distributed ledger system. |
| 29 | Secure and reliable data access, Enhanced smart contract utility, Cross-chain interoperability                                            | Enables smart contracts to access real-world data, solving the limitation of on-chain data sources.                                                                                                                           |
| 30 | Efficiency Gains, Connectivity, Knowledge Sharing, Cost Savings, Interoperability, Scalability, Enhanced Security                         | Interoperability between different blockchains, scalability issues in blockchain technology, fragmented blockchain landscape.                                                                                                 |
| 31 | High Scalability, Low Transaction Latency, Security, Energy Efficiency, Interoperability, Flexibility in Custom Blockchain Creation       | Scalability limitations of existing blockchains, high energy consumption and slow transaction speeds, interoperability challenges.                                                                                            |
| 32 | High Scalability, Low Transaction Costs, Fast Transaction Processing, Energy Efficiency, Enhanced Security                                | Scalability and high transaction costs in blockchain networks, latency issues and energy consumption.                                                                                                                         |
| 33 | Enhanced Privacy, Reduced Transaction Costs, Streamlined Business Operations, Regulatory Compliance, Interoperability with Legacy Systems | Inefficiencies in traditional inter-organizational transactions, privacy concerns in public blockchains, integration with existing business processes.                                                                        |
| 34 | High Scalability, Enhanced Security, Low Transaction Fees, Energy Efficiency, Suitable for High-Throughput Applications                   | Scalability issues in traditional blockchains, high gas fees, limitations in processing large volumes of transactions.                                                                                                        |
| 35 | High Scalability, Energy Efficiency, Secure Blockchain Infrastructure, Democratized Access, Interoperability, Sustainability              | Scalability and energy consumption issues in traditional blockchains, need for a more sustainable and inclusive blockchain ecosystem.                                                                                         |
| 36 | Blockchain Interoperability, Scalability, Customizability, Reduced Transaction Costs, Energy Efficiency                                   | Limited interoperability between different blockchain networks, scalability issues, complex governance and slow transaction speeds.                                                                                           |
| 37 | High Scalability, Low Transaction Costs, High Transaction Speed, Enhanced Security, Energy Efficiency                                     | Scalability challenges in existing blockchains, high costs and slow transaction speeds, providing a secure and efficient platform for modern digital applications.                                                            |
| 38 | Combination of Bitcoin's security and Ethereum's flexibility, Mobile-Friendly, Energy Efficiency, Business-Oriented Blockchain Solutions  | Need for secure and flexible blockchain solutions for businesses, blockchain accessibility on mobile devices, integration of smart contracts in business processes.                                                           |

|    |                                                                                                                                                          |                                                                                                                                                              |
|----|----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 39 | High Customizability, Efficient Asset Management, Business-Oriented Features, Enhanced Security, Low Transaction Costs                                   | Need for efficient asset management in businesses, requirement for customizable blockchain solutions, transaction cost and speed in enterprise applications. |
| 40 | Enhanced Security for Identity and Data, Scalability, Interoperability, Flexible and Customizable, Efficient Transaction Processing                      | Security and trust issues in digital identity and data management, interoperability challenges in blockchain networks, scalability concerns.                 |
| 41 | User-Friendly Interface, Customizability, Low Entry Barrier for Token Creation, Scalability, Decentralized Exchange Features                             | Complexity in creating and managing custom tokens, accessibility barriers to blockchain technology, need for scalable and customizable blockchain solutions. |
| 42 | High Scalability, Real-World Data Integration, Efficient Smart Contract Execution, Off-Chain Scaling, Reduced Transaction Fees                           | Scalability issues in traditional blockchain networks, the gap between real-world data and smart contracts, transaction cost and speed.                      |
| 43 | Blockchain Interoperability, Scalability, Decentralized Identity Solutions, Enhanced Security                                                            | Lack of interoperability between different blockchain networks, scalability issues and the need for a unified decentralized identity framework.              |
| 44 | Low Energy Consumption, Scalability, Empowerment of Users, Enhanced Privacy                                                                              | Scalability and energy consumption of traditional blockchains, centralization of data, lack of user autonomy in traditional app frameworks.                  |
| 45 | High Scalability, Low Transaction Fees, Fast Transaction Speeds, Energy Efficiency                                                                       | Scalability issues in blockchain networks, high transaction costs, slow processing times and energy consumption concerns.                                    |
| 46 | Accessibility for Developers, Customizable Blockchain Applications, Strong Developer Community, Focus on User Experience, Scalability through Sidechains | Complexity of blockchain application development, accessibility of blockchain technology and scalability issues.                                             |

### 5.3.1. Benefits summarization

1. Accessibility and Inclusion
2. Cost Efficiency
3. Security and Privacy
4. Interoperability and Connectivity
5. Efficiency and Speed
6. Customizability and Flexibility
7. Sustainability and Environmental Impact
8. Innovation and Developer Support
9. Economic and Business Optimization

### 5.3.2. Problems addressed summarization

1. Digital Transformation and Accessibility
2. Urban and Environmental Challenges
3. Blockchain Adoption and Interoperability
4. Healthcare and Data Management
5. Mobility and Transportation Efficiency
6. IoT Integration and Smart City Development
7. Sustainability and Carbon Emissions
8. Blockchain Scalability and Energy Consumption
9. Digital Identity and Data Security
10. Economic and Business Process Optimization
11. Financial Inclusion and Cross-Border Payments

### 5.3.3 Conclusion

The data collected for the BCTs of the dataset in this paper, reveal that they aim to revolutionize traditional systems by enhancing accessibility, privacy, security and efficiency and also strive to tackle pressing urban and environmental challenges. We can see a targeted approach towards creating inclusive, sustainable and interconnected frameworks that align closely with the Sustainable Development Goals (SDGs). The BCTs of the dataset address critical issues such as urban congestion, pollution, inefficient resource use and digital inequality, presenting a potential shift towards smarter, cleaner and more equitable systems. By leveraging BCTS, sectors ranging from healthcare to finance can experience transformative changes, characterized by reduced costs, enhanced transparency and improved governance structures. Particularly, the emphasis on interoperability and decentralized operations reveals a move towards more democratic and participatory models of governance and service delivery.

Furthermore, the integration of BCTS within the realms of IoT and smart cities highlights the potential for these technologies to support the next wave of urban and environmental innovation. By providing a secure and efficient framework for digital identities and transactions, BCTS sets the foundation for a more sustainable, efficient and user-centric urban ecosystem.

In conclusion, the benefits and problems addressed by BCTS, as outlined in this research highlights the technology's potential to significantly impact on multiple aspects of both the social and the economic life of people. This analysis provides a clear indication that BCTS are not merely technological advancements but are pivotal in driving forward a sustainable, inclusive and interconnected future.

### 5.3.4. Benefits and Barriers results

Blockchain technology, widely recognized for its innovative and unparalleled capabilities, offers numerous benefits, while also presenting certain challenges. A major advantage of blockchain, that we have seen many times throughout this paper and we can also see in almost every blockchain in the data of this paper, is its potential to enhance transparency and efficiency. This characteristic is clearly demonstrated by blockchain solutions like "Universa", which we have seen finds applications in sectors such as economy, safety, transparency, education and health, showcasing its diverse utility.

As we have seen, the alignment of blockchain solutions with the United Nations Sustainable Development Goals (SDGs) is a recurring theme in this paper. Projects like "Responsible Box" [15] and "DOVU" [16], which we saw above, embody this alignment, focusing on sustainability and ecological impacts. These solutions are not only great tools for making operational processes more straightforward and efficient but also align with broader goals, a point that has been emphasized multiple times in previous sections, such as industry innovation and infrastructure development.

However, the practical utility of blockchain technologies, an important topic that has been repeatedly mentioned and analyzed throughout this paper, must be balanced against their costs. The

cost-benefit analysis is crucial in sectors where cost-saving is a primary driver for technology adoption. For instance, the financial models of blockchain solutions, especially those involving tokenization like "DOVU" [16], highlight the economic implications and the need for cost-effective solutions.

In terms of barriers, the high implementation costs of blockchain solutions, can limit access for smaller entities and marginalized communities. This aspect challenges the fairness and broad adoption of blockchain technology. Moreover, the comparison of blockchain with traditional systems in terms of cost-effectiveness and practicality, is essential. For instance, the data shows varying costs and TRL (Technology Readiness Level) for different solutions, reinforcing the need for comparison and evaluation.

Privacy and data protection, particularly in private blockchains, also pose challenges. While solutions like "Universa" [14] are public and decentralized, emphasizing transparency and open access, the discussion of private blockchains in other parts of the paper shows that they offer more controlled environments with heightened privacy. However, this can lead to different challenges compared to public blockchains like "Universa" [14], such as potential vulnerabilities in decentralization and data manipulation.

In summary, the benefits of blockchain technology, such as its capacity to enhance transparency, efficiency and alignment with global development goals, are significant. This chapter brings together the key points discussed throughout the paper, highlighting the strengths and challenges of blockchain technology, emphasizing that understanding and addressing its barriers, such as cost, privacy concerns and comparison with traditional systems, is crucial for its effective implementation. The data in this paper provides a rich context for understanding these aspects, allowing for a comprehensive analysis of blockchain technology's potential and challenges in various sectors. We've seen how solutions like "Universa" [14] and "DOVU" [16] can improve transparency, efficiency and contribute to global development goals. However, it's also clear that we need to carefully consider the costs, privacy issues and how these technologies compare with traditional systems. This final chapter wraps up our discussion, offering a clear overview of the potential and limitations of blockchain in various sectors, based on the comprehensive analysis provided in the earlier sections of this paper.

#### 5.4. Core characteristics of the BCT solutions

Table 3: Core characteristics

| # | <u>BCT type</u> | <u>Consensus mechanism</u> | <u>TRL</u> | <u>Application domain (sector)</u>           | <u>Level of governance</u> | <u>Types of decisions</u>                  |
|---|-----------------|----------------------------|------------|----------------------------------------------|----------------------------|--------------------------------------------|
| 1 | Public          | Proof of stake             | TRL9       | Economy,safety,transparency,education,health | Micro                      | Operational, technical                     |
| 2 | Public          | Undisclosed                | TRL7       | Environment                                  | N/A                        | Environmental, Operational, Sustainability |
| 3 | Public          | Proof of Carbon            | TRL7       | Ecology                                      | Micro                      | Environmental, Operational, Sustainability |
| 4 | Public          | Proof of stake             | TRL9       | Accessibility, economy/finance               | Meso                       | Financial, Strategic                       |

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|    |             |                                                      |      |                                                                                                                                                       |               |                              |
|----|-------------|------------------------------------------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|------------------------------|
| 5  | Public      | Undisclosed                                          | TRL6 | Public transportation                                                                                                                                 | Micro         | Operational, technical       |
| 6  | Hybrid      | Proof of authority                                   | TRL9 | Healthcare                                                                                                                                            | Macro         | Policy, Strategic            |
| 7  | Hybrid      | Undisclosed                                          | TRL8 | Transportation                                                                                                                                        | Meso          | Operational, Policy          |
| 8  | Hybrid      | Undisclosed                                          | TRL7 | Identification                                                                                                                                        | Macro         | Strategic, Technical         |
| 9  | Hybrid      | Undisclosed                                          | TRL9 | Mobile health, wellness programs,<br>environmental sustainability                                                                                     | Micro         | Environmental, Operational   |
| 10 | Public      | DAG (Directed Acyclic Graph)<br>with Smart Contracts | TRL6 | Technology and IoT, Data Services and Analytics,<br>Environmental Monitoring, Smart Cities,<br>Agriculture, Agriculture, Transportation and Logistics | Micro + Macro | Operational, Policy          |
| 11 | Public      | Undisclosed                                          | TRL9 | Data Management and Analytics,<br>Information Technology Infrastructure                                                                               | N/A           | Strategic, Technical         |
| 12 | Undisclosed | Undisclosed                                          | TRL9 | Urban Development, Technology Integration                                                                                                             | N/A           | Strategic, Technical         |
| 13 | Public      | Proof of stake                                       | TRL9 | Safety, oversight                                                                                                                                     | Micro         | Strategic, Technical         |
| 14 | Public      | Undisclosed                                          | TRL9 | Safety on the internet                                                                                                                                | Meso          | Strategic, Technical         |
| 15 | Public      | Undisclosed                                          | TRL9 | Governance, Legal Technology                                                                                                                          | Micro         | Strategic, Technical         |
| 16 | Undisclosed | Undisclosed                                          | TRL7 | Sustainability, environment protection                                                                                                                | Macro         | Policy, Strategic, Financial |
| 17 | Public      | Proof of stake                                       | TRL9 | Transactions, finance, transparency, sustainability                                                                                                   | Macro         | Financial, Strategic         |
| 18 | Private     | Modular and pluggable consensus                      | TRL8 | Enterprise solutions, finance, Supply Chain, Healthcare                                                                                               | Micro + Meso  | Operational, Strategic       |
| 19 | Private     | Notary-based                                         | TRL8 | Finance, Trade                                                                                                                                        | Micro         | Operational, Compliance      |

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|    |         |                                                                           |      |                                                                                                                                                           |              |                                                                  |
|----|---------|---------------------------------------------------------------------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------------------------------------------------------------------|
| 20 | Private | Istanbul BFT, Raft                                                        | TRL7 | Finance, Supply Chain                                                                                                                                     | Meso         | Operational, Strategic                                           |
| 21 | Public  | Delegated Proof of Stake (DPoS)                                           | TRL8 | Decentralized applications, smart contracts, commercial-scale dApps                                                                                       | Micro        | Operational, Strategic (in dApp ecosystem)                       |
| 22 | Public  | Liquid Proof of Stake (LPoS)                                              | TRL8 | Decentralized applications, smart contracts, digital assets                                                                                               | Macro        | Operational, Strategic (in blockchain ecosystem)                 |
| 23 | Public  | Delegated Byzantine Fault Tolerance (dBFT)                                | TRL8 | Smart contracts, decentralized applications, digital asset management                                                                                     | Macro        | Operational, Strategic (in blockchain and dApp ecosystem)        |
| 24 | Public  | Proof of stake                                                            | TRL7 | Decentralized applications, smart contracts, digital transactions                                                                                         | Macro        | Operational, Strategic (in blockchain ecosystem)                 |
| 25 | Public  | Proof of authority                                                        | TRL7 | Supply chain management, business processes, Internet of Things (IoT)                                                                                     | Macro        | Operational, Strategic (in supply chain and business management) |
| 26 | Public  | Proof of stake                                                            | TRL9 | Blockchain infrastructure, business processes, supply chain, Customizable Child Chains, Decentralized Applications (DApps), Scalable Blockchain Solutions | Macro        | Operational, Strategic (in blockchain infrastructure), Technical |
| 27 | Public  | Stellar Consensus Protocol (SCP), a unique federated consensus mechanism. | TRL9 | Financial services, Cross-Border Payments, Remittances, Asset Tokenization, Mobile Payments                                                               | Macro        | Operational, Financial, Strategic                                |
| 28 | Public  | Directed Acyclic Graph (DAG)                                              | TRL8 | Internet of Things (IoT), Smart Cities, Data Integrity, Microtransactions, Data and Value Transfer                                                        | Macro + Meso | Operational, Strategic, Technical                                |

## Ανασκόπηση εφαρμογών και υποδομών για την τεχνολογία blockchain

|    |         |                                                                                |      |                                                                                                           |       |                                                                 |
|----|---------|--------------------------------------------------------------------------------|------|-----------------------------------------------------------------------------------------------------------|-------|-----------------------------------------------------------------|
| 29 | Public  | Proof of stake                                                                 | TRL7 | Smart contracts, Data integration, Off-chain computation                                                  | Macro | Operational, Strategic (in smart contract and data integration) |
| 30 | Public  | Proof of stake                                                                 | TRL9 | Decentralized Finance (DeFi), IoT, Privacy, Smart Contracts, Interoperability                             | Macro | Strategic, Operational                                          |
| 31 | Public  | Avalanche Consensus Protocol                                                   | TRL9 | Decentralized Finance (DeFi), Asset Tokenization, NFTs, Enterprise Blockchain Solutions                   | Macro | Strategic, Operational, Financial                               |
| 32 | Public  | Proof of History (PoH) combined with Proof of Stake (PoS)                      | TRL9 | Decentralized Finance (DeFi), Non-Fungible Tokens (NFTs), Decentralized Exchanges, Gaming                 | Macro | Strategic, Operational, Financial                               |
| 33 | Private | Notary-based Consensus (unique to Corda, focusing on legal agreement finality) | TRL9 | Finance, Insurance, Healthcare, Government, Supply Chain                                                  | Meso  | Operational, Strategic, Regulatory                              |
| 34 | Public  | Practical Byzantine Fault Tolerance (PBFT) combined with Sharding              | TRL8 | Decentralized Finance (DeFi), Digital Advertising, Gaming, Entertainment, Tokenization                    | Macro | Operational, Strategic, Financial                               |
| 35 | Public  | Ouroboros, a unique proof-of-stake algorithm                                   | TRL8 | Decentralized Finance (DeFi), Education, Retail, Agriculture, Government                                  | Macro | Strategic, Operational, Environmental                           |
| 36 | Public  | Tendermint (Byzantine Tolerance) BFT Fault                                     | TRL8 | Interoperable Blockchain Networks, Decentralized Finance (DeFi), Scalable dApps, Cross-Chain Transactions | Macro | Strategic, Technical, Operational                               |

## Ανασκόπηση εφαρμογών και υποδομών για την τεχνολογία blockchain

|    |        |                                                                                                                                                                          |      |                                                                                                         |       |                                   |
|----|--------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|---------------------------------------------------------------------------------------------------------|-------|-----------------------------------|
| 37 | Public | Secure Proof of Stake (SPoS)                                                                                                                                             | TRL8 | Decentralized Finance (DeFi), Non-Fungible Tokens (NFTs),<br>Smart Contracts, Enterprise Solutions      | Macro | Strategic, Operational, Technical |
| 38 | Public | Proof of stake                                                                                                                                                           | TRL8 | Decentralized Applications (DApps), Business Applications,<br>Mobile Solutions, Smart Contracts         | Macro | Strategic, Operational, Financial |
| 39 | Public | Proof of Importance (Pol)<br><br>a unique algorithm that rewards users based on their transaction frequency and amount, encouraging active participation in the network. | TRL8 | Enterprise Solutions, Asset Management, Supply Chain, Notarization Services                             | Macro | Operational, Strategic, Financial |
| 40 | Public | VBFT, a combination of Proof of Stake (PoS), Byzantine Fault Tolerance (BFT) and Variable Random Function (VRF)                                                          | TRL8 | Digital Identity, Data Exchange, Decentralized Finance (DeFi),<br>Supply Chain, Healthcare              | Macro | Strategic, Operational, Technical |
| 41 | Public | Leased Proof of Stake (LPoS)                                                                                                                                             | TRL8 | Tokenization, Decentralized Finance (DeFi),<br>Custom Cryptocurrency Creation, DApps                    | Macro | Operational, Strategic, Technical |
| 42 | Public | Hybrid Proof-of-Work (PoW) and Byzantine Fault Tolerance (BFT) system                                                                                                    | TRL7 | Decentralized Applications (DApps), Fintech, Supply Chain, IoT, Gaming                                  | Macro | Strategic, Operational, Technical |
| 43 | Public | Loop Fault Tolerance (LFT), a modified BFT algorithm                                                                                                                     | TRL8 | Interoperable Blockchain Networks, Decentralized Identity (DID),<br>Decentralized Applications (DApps), | Macro | Strategic, Technical, Operational |

|    |        |                                                                            |      |                                                                                                      |       |                                              |
|----|--------|----------------------------------------------------------------------------|------|------------------------------------------------------------------------------------------------------|-------|----------------------------------------------|
|    |        |                                                                            |      | Cross-Chain Transactions                                                                             |       |                                              |
| 44 | Public | No global consensus uses Distributed Hash Tables (DHT) akin to BitTorrent. | TRL7 | Peer-to-Peer Applications, Social Networks, Supply Chain, Cooperative Platforms, Crowdfunding        | Meso  | Operational, Community Governance, Strategic |
| 45 | Public | Effective Proof-of-Stake (EPoS)                                            | TRL8 | Decentralized Finance (DeFi), Non-Fungible Tokens (NFTs), Gaming, Decentralized Applications (DApps) | Macro | Strategic, Technical, Operational            |
| 46 | Public | Delegated Proof of Stake (DPoS)                                            | TRL7 | Decentralized Applications (DApps), Blockchain Development, Education, Data Management               | Macro | Strategic, Technical, Operational            |

**Types of decisions:**

- **Operational:** Decisions related to the day-to-day management and administration of a blockchain system or application. This includes routine tasks, maintenance, and minor adjustments to ensure smooth operation.
- **Community Governance:** Decisions made collectively by the community or network participants, often through consensus mechanisms or voting. These decisions can relate to changes in the network, protocol updates, or other community-driven initiatives.
- **Environmental:** Decisions that pertain to the environmental impact of blockchain technology, such as energy consumption, carbon footprint, and sustainability measures.
- **Strategic (in dApp ecosystem):** Long-term planning and decision-making within the decentralized application (dApp) ecosystem. This involves determining the direction, goals, and priorities for a particular dApp or a set of dApps.
- **Regulatory:** Decisions related to compliance with laws and regulations. In the blockchain context, this can involve adhering to financial regulations, data protection laws, and other legal requirements.
- **Technical:** Decisions that involve the technical aspects of blockchain technology. This includes choices about blockchain protocol, software updates, system architecture, and security measures.
- **Strategic:** Broad, long-term planning and decision-making that affects the future direction and priorities of a blockchain system, network, or organization. This involves setting goals, allocating resources, and making key decisions that shape the future of the technology or organization.
- **Policy:** High-level decisions that involve setting rules, standards, or guidelines for a blockchain network or system. This can include governance policies, ethical guidelines, or standards for network participation.
- **Compliance:** Decisions related to ensuring that blockchain technology and its applications comply with existing laws, regulations, and internal policies. This includes monitoring and adapting to changes in the legal and regulatory landscape.

- **Financial:** Decisions regarding the financial aspects of blockchain technology, such as funding, budgeting, revenue models, and financial management within a blockchain project or organization.
- 

### BCT type statistics

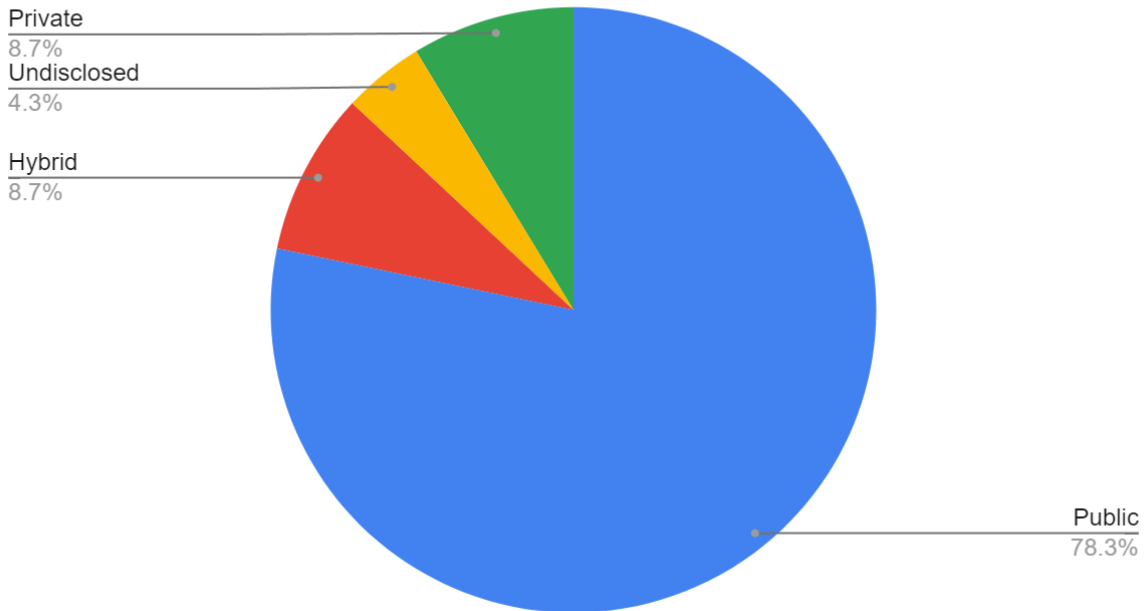


*Image 2: BCT type statistics*

- Public : 78.3%
- Private : 8.7%
- Hybrid : 8%
- Undisclosed : 4%

In analyzing the blockchain types within the dataset, we observe a significant skew towards public blockchains, which constitute 78.3% of the total. This dominance may be partly attributed to the inherent transparency and open-access nature of public blockchains, making them more readily identifiable and researchable. In contrast, private blockchains, accounting for 8.7% of the dataset, are typically used within specific organizational contexts and may not be as publicly accessible, thus potentially underrepresented in studies relying on publicly available data. Hybrid blockchains, blending characteristics of both public and private types, represent 8%, reflecting an interest in versatile blockchain solutions. The remaining 4% of undisclosed types could suggest either projects in early developmental stages or a strategic preference for confidentiality. This distribution highlights not only current trends in blockchain usage but also the influence of accessibility and visibility on research findings in this domain.

## Consensus mechanisms statistics

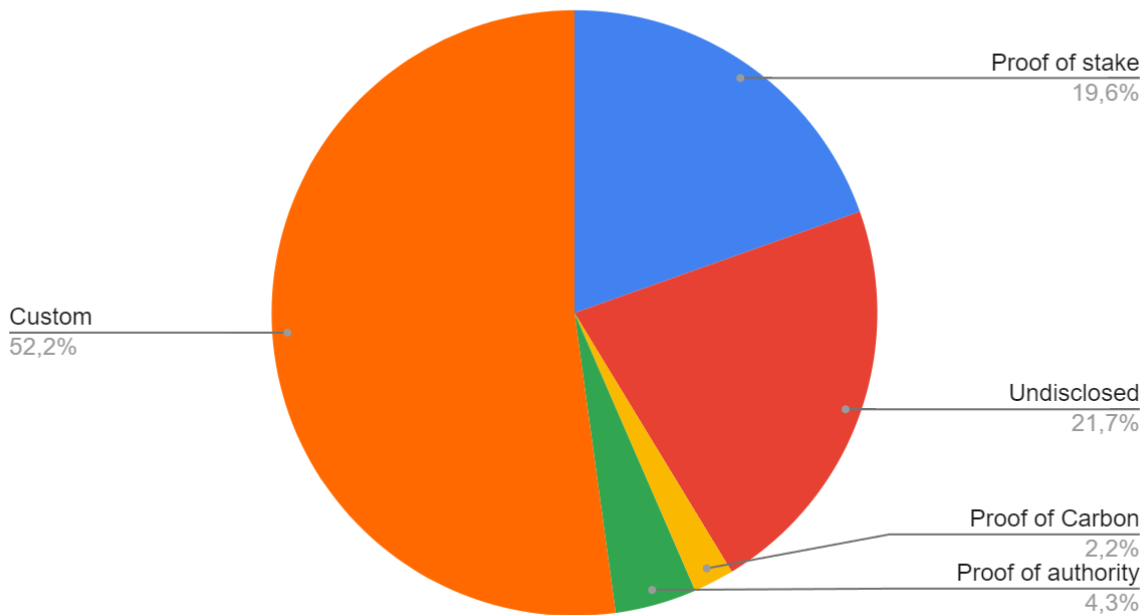


*Image 3: Consensus mechanisms statistics*

- Custom : 52.2%
- Proof of stake : 19.6%
- Undisclosed : 21.7%
- Proof of authority : 4.3%
- Proof of carbon : 2.2%

In the dataset, the consensus mechanisms of blockchain solutions exhibit a diverse range. Notably, 52.2% use a custom consensus mechanism, which often involves a combination of elements from multiple mechanisms, either those represented in the dataset or others. This custom approach reflects a trend towards tailored solutions catering to specific needs. Proof of Stake is utilized by 19.6%, aligning with the industry's shift towards more energy-efficient consensus methods (meaning other than the highly energy-consuming “proof of work (PoW)”, which is very well known as the consensus mechanism of Bitcoin). An equal 21.7% remains undisclosed, suggesting either emerging mechanisms or confidentiality. Proof of Authority and Proof of Carbon with 4.3% and 2.2% respectively, indicating niche but significant roles in the blockchain ecosystem. This distribution underscores the innovative and adaptive nature of consensus mechanisms in blockchain technology.

## TRL statistics

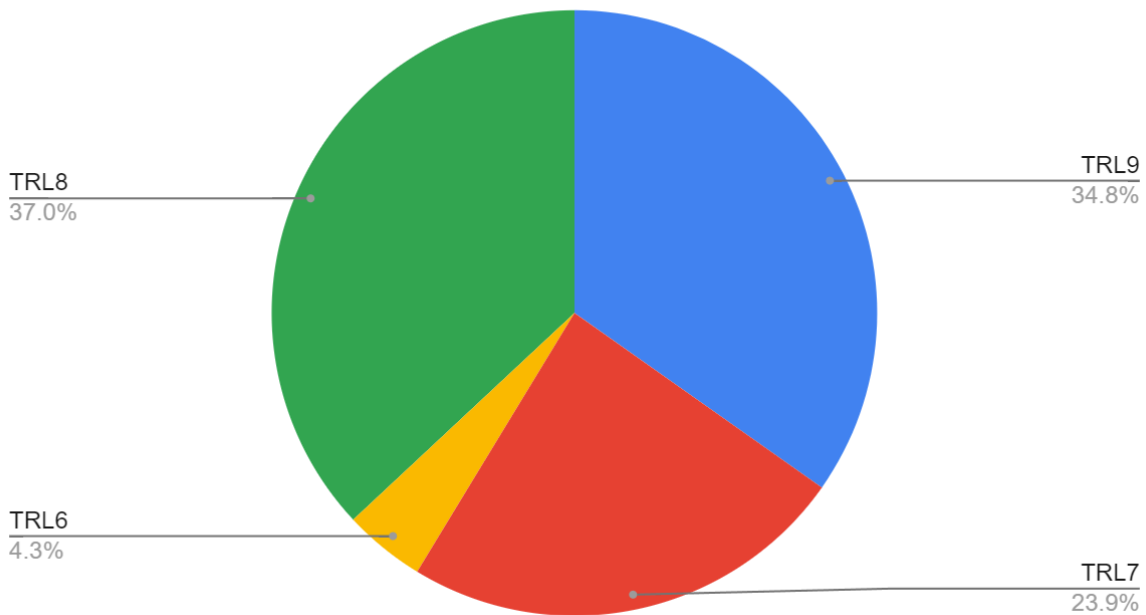


Image 4: TRL statistics

- TRL 8 : 37%
- TRL 9 : 34.8%
- TRL 7 : 23.9%
- TRL 6 : 4.3%

The dataset's Technology Readiness Levels (TRLs) predominantly feature later-stage blockchain developments, with 37% at TRL 8 and 34.8% at TRL 9. This distribution reflects the substantial market demand for mature, operational blockchain solutions across various sectors. The predominance of these advanced stages also indicates a trend towards deploying blockchain technologies that can immediately address real-world applications. However, it is crucial to acknowledge the relative challenge in gathering data on early-stage blockchain projects, represented by 23.9% at TRL 7 and 4.3% at TRL 6. These lesser-known technologies, still in their developmental or prototypical phases, are often underreported and less visible in public domains, leading to their underrepresentation in research-oriented datasets. This dynamic suggests that while the dataset leans towards more developed blockchain solutions, this is partially a consequence of the greater accessibility and visibility of such projects, rather than an exclusive focus on them by the industry.

### Level of governance statistics

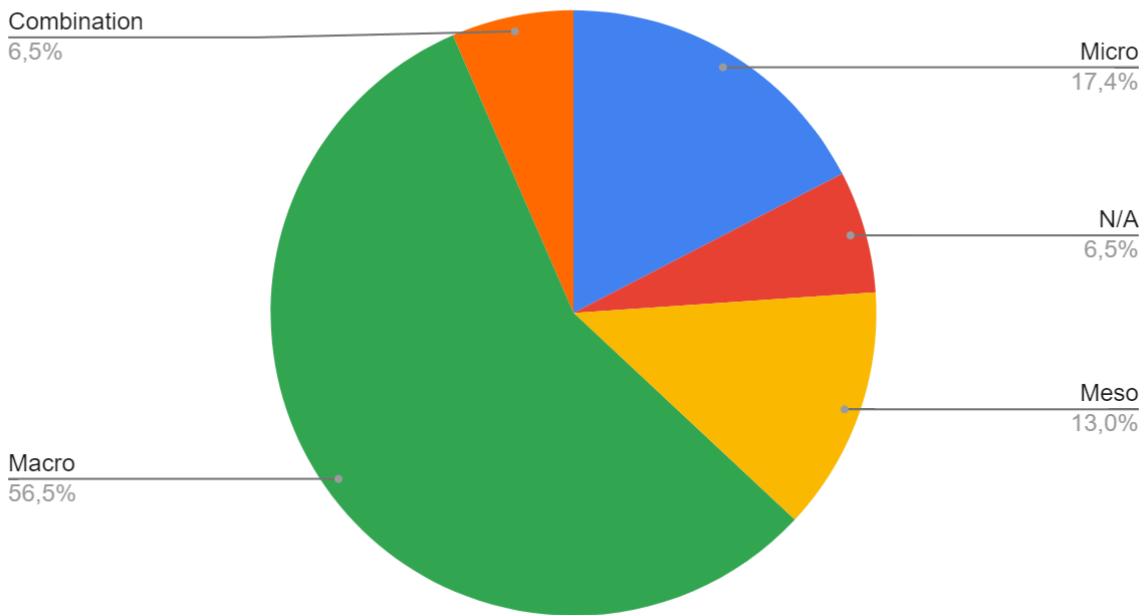


*Image 5: Level of governance statistics*

- Macro : 56.5%
- Micro : 17.4%
- Meso : 13%
- N/A : 6.5%
- Combination : 6.5%

A dominant focus on macro-level governance, representing 56.5%, reflects the research's aim towards BCTs that offer societal benefits, which explains the higher percentage at this level. Micro-level and meso-level governance account for 17.4% and 13%, respectively, showing their importance in establishing the technology's basic structure and managing processes. The presence of combined governance levels in 6.5% of the cases suggests an emerging interest in hybrid governance models, blending various levels to suit specific requirements of blockchain projects. The "N/A" category, also at 6.5%, hints at possibly evolving governance structures or undefined models at the current stage of development, indicating a diverse and adaptable governance landscape within BCTs. This distribution highlights the significant potential of BCTs to drive large-scale societal changes, particularly through macro-level governance, in line with the goal of leveraging blockchain for broad societal benefits.

Types of decisions statistics

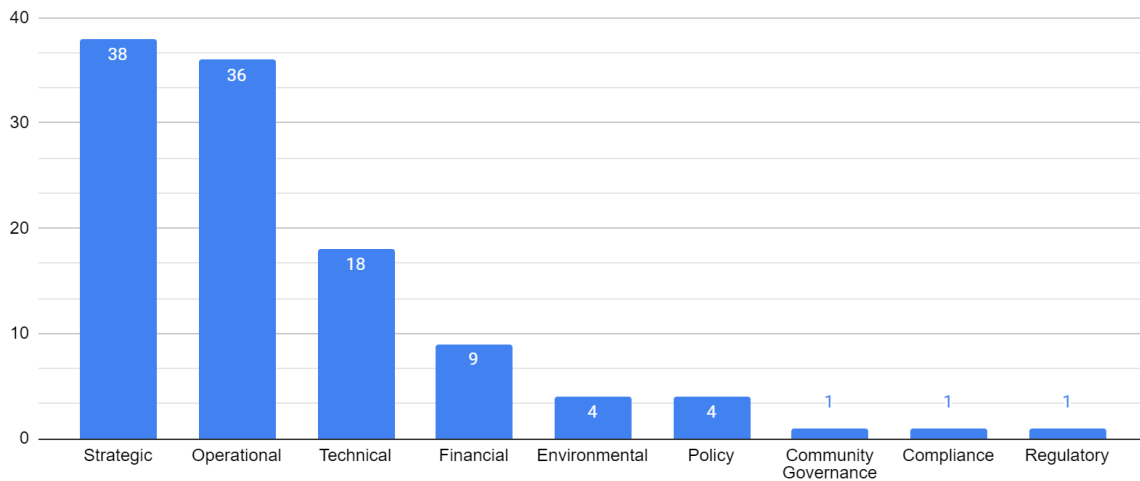


Image 6: Types of decisions statistics

### 5.5. SDG connections

1. SDG 4: Quality education SDG 7: Affordable and Clean Energy
2. SDG 11: Sustainable Cities and Communities SDG 13: Climate Action SDG 15: Life on Land
3. SDG 11: Sustainable Cities and Communities SDG 13: Climate Action
4. SDG 9: Industry, Innovation and Infrastructure
5. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 13: Climate Action SDG 15: Life on Land
6. SDG 3: Good Health and well-being
7. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 13: Climate Action SDG 15: Life on Land
8. SDG 16: Peace, Justice and Strong Institutions
9. SDG 11: Sustainable Cities and Communities SDG 13: Climate Action SDG 15: Life on Land
10. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 12: Responsible Consumption and Production SDG 13: Climate Action SDG 17: Partnerships for the Goals
11. SDG 7: Affordable and Clean Energy SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 12: Responsible Consumption and Production
12. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities
13. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 16: Peace, Justice and Strong Institutions
14. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 16: Peace, Justice and Strong Institutions SDG 17: Partnerships for the Goals
15. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 13: Climate Action
16. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 12: Responsible Consumption and Production SDG 13: Climate Action SDG 17: Partnerships for the Goals
17. SDG 16: Peace, Justice and Strong Institutions
18. SDG 8: Decent Work and Economic Growth, SDG 9: Industry, Innovation and Infrastructure
19. SDG 9: Industry, Innovation and Infrastructure

20. SDG 9: Industry, Innovation and Infrastructure
21. SDG 9: Industry, Innovation, and Infrastructure
22. SDG 9: Industry, Innovation and Infrastructure SDG 17: Partnerships for the Goals
23. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities
24. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
25. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
26. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
27. SDG 8: Decent Work and Economic Growth SDG 9: Industry, Innovation and Infrastructure SDG 10: Reduced Inequalities SDG 17: Partnerships for the Goals
28. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 12: Responsible Consumption and Production
29. SDG 9: Industry, Innovation and Infrastructure SDG 17: Partnerships for the Goals
30. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 17: Partnerships for the Goals
31. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production SDG 13: Climate Action
32. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
33. SDG 8: Decent Work and Economic Growth SDG 9: Industry, Innovation and Infrastructure SDG 17: Partnerships for the Goals
34. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
35. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities SDG 13: Climate Action
36. SDG 9: Industry, Innovation and Infrastructure SDG 17: Partnerships for the Goals
37. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
38. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities
39. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
40. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities
41. SDG 9: Industry, Innovation and Infrastructure SDG 10: Reduced Inequalities
42. SDG 9: Industry, Innovation and Infrastructure SDG 11: Sustainable Cities and Communities
43. SDG 9: Industry, Innovation and Infrastructure SDG 17: Partnerships for the Goals
44. SDG 11: Sustainable Cities and Communities SDG 12: Responsible Consumption and Production SDG 13: Climate Action
45. SDG 9: Industry, Innovation and Infrastructure SDG 12: Responsible Consumption and Production
46. SDG 4: Quality education SDG 9: Industry, Innovation and Infrastructure

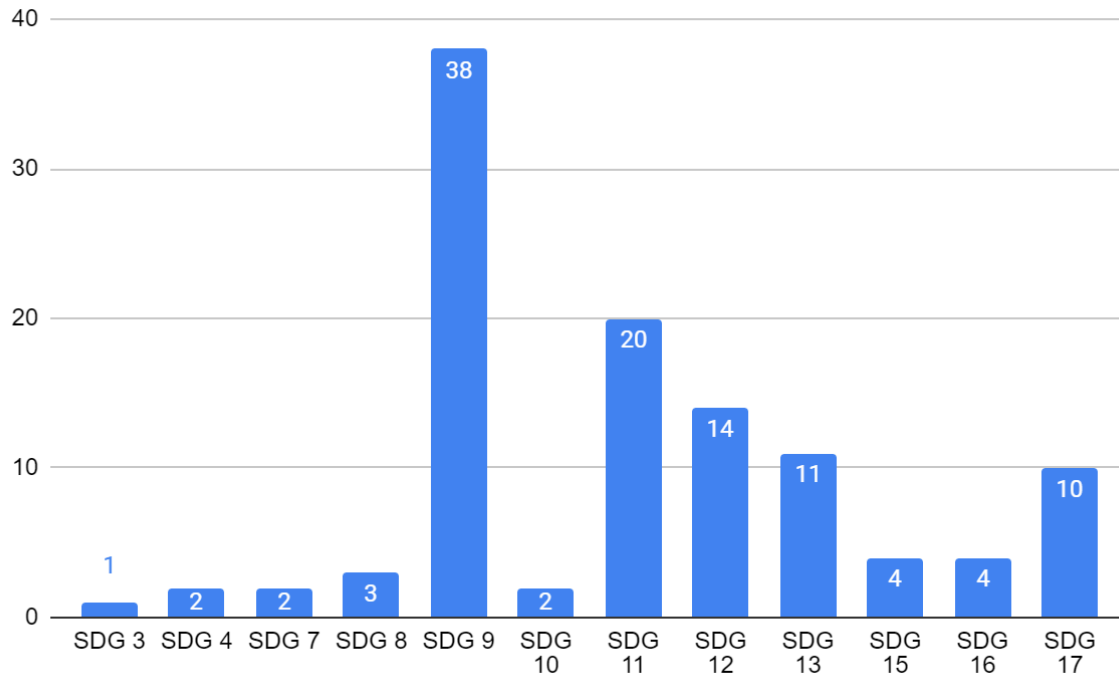


Image 7: SDGs statistics

- SDG 1 : 0 BCTs
- SDG 2 : 0 BCTs
- SDG 3 : 1 BCTs
- SDG 4 : 2 BCTs
- SDG 5 : 0 BCTs
- SDG 6 : 0 BCTs
- SDG 7 : 2 BCTs
- SDG 8 : 3 BCTs
- SDG 9 : 38 BCTs
- SDG 10 : 2 BCTs
- SDG 11 : 20 BCTs
- SDG 12 : 14 BCTs
- SDG 13 : 11 BCTs
- SDG 14 : 0 BCTs
- SDG 15 : 4 BCTs
- SDG 16 : 4 BCTs
- SDG 17 : 10 BCTs

1. High Emphasis on Industry, Innovation and Infrastructure (SDG 9):
  - With 38 BCTs linked to SDG 9, there's a significant emphasis on industry, innovation and infrastructure. This trend suggests that blockchain technology is primarily being leveraged to drive technological advancement, foster innovation and build robust infrastructure. The focus could be on improving industrial processes, enhancing innovation in services and products and building infrastructure that supports sustainable development.
2. Sustainable Cities and Communities (SDG 11) and Responsible Consumption and Production (SDG 12):

- The connection of 20 BCTs to SDG 11 and 14 to SDG 12 indicates a strong focus on making cities inclusive, safe, resilient and sustainable. It also shows an emphasis on ensuring sustainable consumption and production patterns. Blockchain could be used for urban planning, resource management, waste reduction and ensuring efficient use of resources.
3. Climate Action (SDG 13):
    - The combined connection of 11 BCTs to SDG 13 suggests a significant role for blockchain in addressing climate change. Based on the dataset of this paper and the information gathered from the BCTs of this dataset, this may involve tracking carbon footprints, improving transparency in emission reporting and promoting sustainable practices across various industries. Beyond these applications, the potential of blockchain extends to fostering more sustainable societies and cities. Thanks to the enormous potential of Blockchain Technology (BCT), it can play a pivotal role in supporting the development of smart cities, enabling efficient resource management, renewable energy distribution and waste reduction through improved supply chain tracking and asset management (similar to what some of the BCTs of the dataset are providing). Additionally, the integration of blockchain with other emerging technologies like IoT, AI and big data can further enhance environmental monitoring, optimize energy use and facilitate informed decision-making, paving the way for more resilient and adaptable urban environments.
  4. Partnerships for the Goals (SDG 17):
    - The connection of 10 BCTs to SDG 17 implies that blockchain is seen as a tool for enhancing global partnerships. It could facilitate collaboration across borders, sectors and institutions, thereby contributing to the achievement of all the SDGs.
  5. Moderate Connection to Quality Education (SDG 4), Affordable and Clean Energy (SDG 7), Decent Work and Economic Growth (SDG 8) and Life on Land (SDG 15):
    - A moderate number of BCTs are linked to these goals, indicating that while they are not the primary focus, blockchain technology is still contributing to these areas.
  6. Minimal or No Connection to Several SDGs:
    - Notably, there are no BCTs linked to SDGs 1, 2, 5, 6 and 14 and only minimal linkage to SDGs 3, 10 and 16. This could point to untapped potential or current challenges in applying blockchain technology to these specific areas. For instance, goals related to no poverty, zero hunger, gender equality, clean water and sanitation and life below water may require more targeted interventions where blockchain technology may not be directly applicable or has not yet been leveraged effectively.

There's potential for exploring how blockchain can contribute to less represented SDGs. Partnerships with organizations focusing on poverty, hunger, gender equality, water sanitation and marine life could be beneficial. The data indicates the need for further research and innovative approaches to integrate blockchain in diverse fields, aligning with a broader range of SDGs.

This analysis shows that while blockchain technology is significantly contributing to certain SDGs, there is room for broader application across a more diverse range of goals. Understanding the reasons behind this distribution and exploring how blockchain can address the gaps can provide a more inclusive and comprehensive approach to leveraging technology for sustainable development.

As we analyze the findings from the connections between the Blockchain Technology Solutions (BCTs) presented in the dataset of this paper and the 17 Sustainable Development Goals (SDGs), it becomes crucial to re-emphasize the foundational role these linkages play within the scope of our research. This paper has persistently emphasized the significance of the connection between BCTs and SDGs throughout the discourse of this study.

In this part of the paper, when we look closely at how blockchain technologies relate to specific Sustainable Development Goals (SDGs), we're doing more than just putting numbers together. We're really getting to see how new tech can work together with our goals for a better world. Throughout our paper, we've been paying a lot of attention to this connection because it's really important.

This research isn't just about showing where BCTs are already helping, it's also about looking ahead, thinking about new ideas and finding new ways to use BCTs. As this paper approaches its conclusion, the focus remains on this link between blockchain and the goals because it's a key part of this study. It helps us see what blockchain can do now and imagine all the great things it could do in the future to help make the world a better and fairer place for everyone.

## 5.6. Application / Infrastructure

Table 4: Applications/Infrastructure

| #  | <u>Name of BCT solution</u>       | <u>Type of solution</u> |
|----|-----------------------------------|-------------------------|
| 1  | Universa                          | Application             |
| 2  | Responsible Box                   | Application             |
| 3  | DOVU                              | Application             |
| 4  | SmartKey                          | Application             |
| 5  | Observatory of Urban Mobility     | Application             |
| 6  | Personal Health Record OS (phrOS) | Application             |
| 7  | IoMob                             | Application             |
| 8  | XignIn City                       | Application             |
| 9  | Changers CO2 Fit App              | Application             |
| 10 | DataBroker DAO                    | Application             |
| 11 | Smart City Database Platform      | Infrastructure          |
| 12 | GlobalTech.City                   | Application             |
| 13 | Vizsafe                           | Application             |
| 14 | DECODE                            | Application             |
| 15 | Councilbox OVAC                   | Application             |
| 16 | SDG Assessment App                | Application             |
| 17 | Hedera                            | Infrastructure          |
| 18 | Hyperledger Fabric                | Infrastructure          |
| 19 | Corda by R3                       | Infrastructure          |

|    |                            |                |
|----|----------------------------|----------------|
| 20 | Quorum                     | Infrastructure |
| 21 | EOS.IO                     | Infrastructure |
| 22 | Tezos                      | Infrastructure |
| 23 | NEO                        | Infrastructure |
| 24 | Algorand                   | Infrastructure |
| 25 | VeChain                    | Infrastructure |
| 26 | Ardor                      | Infrastructure |
| 27 | Stellar                    | Infrastructure |
| 28 | IOTA                       | Infrastructure |
| 29 | Chainlink                  | Infrastructure |
| 30 | Polkadot                   | Infrastructure |
| 31 | Avalanche                  | Infrastructure |
| 32 | Solana                     | Infrastructure |
| 33 | Corda                      | Infrastructure |
| 34 | Zilliqa                    | Infrastructure |
| 35 | Cardano                    | Infrastructure |
| 36 | Cosmos                     | Infrastructure |
| 37 | Elrond                     | Infrastructure |
| 38 | Qtum                       | Infrastructure |
| 39 | NEM (New Economy Movement) | Infrastructure |
| 40 | Ontology                   | Infrastructure |
| 41 | Waves                      | Infrastructure |
| 42 | Aeternity                  | Infrastructure |
| 43 | Icon (ICX)                 | Infrastructure |
| 44 | Holochain                  | Infrastructure |

|    |               |                |
|----|---------------|----------------|
| 45 | Harmony (ONE) | Infrastructure |
| 46 | Lisk          | Infrastructure |

1. Given its broad application in various domains and emphasis on enabling smart city functionalities, **Universa** seems more aligned with **application** characteristics, as it offers specific functionalities built on blockchain for end-users in different sectors.
2. **Responsible Box** appears to be an **application**, focusing on sustainability and product lifecycle management, indicating it provides specific services or functionalities for sustainability efforts.
3. **DOVU** is an **application**, utilizing blockchain to promote sustainable transportation and behaviors, offering specific incentives and functionalities to users.
4. **SmartKey** operates as an **application**, providing specific solutions for integrating blockchain technology with real-world assets and services.
5. **Observatory of Urban Mobility** is an **application**, given its focus on leveraging blockchain for enhancing public transportation systems and urban mobility through data-driven insights.
6. Given its focus on health record management for individuals, **phrOS** aligns with an **application** as it offers specific functionalities to end-users in the healthcare sector.
7. **IoMob** is an **application**, providing a specific service for mobility and transportation integration for end-users.
8. **Xignin City** is an **application**, focusing on digital identity solutions for citizens, offering specific functionalities within the public sector.
9. The **Changers CO2 Fit App** is an **application**, as it directly interacts with end-users by motivating sustainable behaviors through a rewards system.
10. **DataBroker DAO** serves as an **application**, enabling specific functionalities for the exchange of data, which targets businesses and individuals engaged in technology and IoT sectors.
11. **Smart City Database Platform** is an **infrastructure**, as it provides foundational services for data management and integration for smart city applications.
12. **GlobalTech.City** is classified as an **application**, given its emphasis on connecting tech ecosystems and facilitating urban development, though its precise role could border on infrastructure if it primarily enables other applications.
13. **Vizsafe** is an **application**, as it directly engages with end-users to provide safety and oversight functionalities within communities.
14. **DECODE** operates as an **application**, focusing on providing specific solutions for digital identity and privacy for individuals and communities.
15. **Councilbox OVAC** is an **application**, as it offers a specific service for digital governance and legal procedures between citizens and government entities.
16. **SDG Assessment App** is an **application**, as it offers specific functionalities focused on sustainability assessments for businesses, directly addressing end-user needs.
17. **Hedera** is **infrastructure**, given its foundational services in transaction ordering and time-stamping that enable a wide range of applications.
18. **Hyperledger Fabric** is **infrastructure**, as it provides a platform and tools for building blockchain-based applications, especially for enterprise use.
19. **Corda by R3** is **infrastructure**, offering foundational blockchain capabilities specifically tailored for financial and trade applications.
20. **Quorum** is **infrastructure**, as it provides a blockchain platform that supports a variety of applications, with a strong emphasis on enterprise needs.
21. **EOS.IO** is **infrastructure**, due to its role in providing a platform for the development and execution of dApps, with a focus on scalability and user-friendliness.
22. **Tezos** is **infrastructure**, as it offers a foundational layer for building and deploying smart contracts and dApps, with unique features like on-chain governance for protocol upgrades.

23. **NEO** is **infrastructure**, providing a comprehensive platform for the digital economy that supports the creation of dApps and smart contracts.
24. **Algorand** is **infrastructure**, as it provides the underlying technology for fast, secure and efficient creation and operation of decentralized applications on its network.
25. **VeChain** is **infrastructure**, due to its role in providing a foundational platform for supply chain solutions and IoT integration.
26. **Ardor** is **infrastructure**, as it provides a multi-chain platform that enables the creation and management of child chains for various applications.
27. **Stellar** is **infrastructure**, given its foundational services for financial transactions and its role in facilitating payments and asset transfers on a global scale.
28. **IOTA** is **infrastructure**, specifically tailored for IoT applications, offering a scalable and efficient platform for data and value exchange in the IoT ecosystem.
29. **Chainlink** serves as **infrastructure** by providing a critical service (oracles) that enables smart contracts to interact securely with external data, which is essential for their execution based on real-world events and conditions.
30. **Polkadot** is **infrastructure**, as it provides a foundational layer for interoperability between various blockchain networks, enabling them to communicate and share information seamlessly.
31. **Avalanche** is **infrastructure**, due to its role in providing a scalable blockchain platform capable of supporting a wide range of decentralized applications and financial primitives.
32. **Solana** is **infrastructure**, as it offers a high-speed and scalable foundation for building and running decentralized applications, particularly in sectors requiring high throughput.
33. **Corda** is an **infrastructure**, designed specifically for business applications, particularly in finance and insurance, focusing on privacy and interoperability.
34. **Zilliqa** is **infrastructure**, as it provides a scalable and secure platform for building decentralized applications, especially in fields like DeFi and digital advertising.
35. **Cardano** is **infrastructure**, due to its foundational layer that supports the development of various applications with a focus on sustainability, scalability and security.
36. **Cosmos** is **infrastructure**, as it provides the tools and foundation for building an interconnected network of blockchains, enhancing interoperability and scalability across the ecosystem.
37. **Elrond** is **infrastructure**, given its focus on offering a high-performance blockchain solution that supports the development and operation of decentralized applications and services.
38. **Qtum** is **infrastructure**, as it provides a foundational layer for developing and deploying smart contracts and decentralized applications.
39. **NEM** is **infrastructure**, due to its role in facilitating blockchain application development with an emphasis on asset management and efficiency.
40. **Ontology** is **infrastructure**, providing services for digital identity verification and data management across multiple blockchains.
41. **Waves** is **infrastructure**, due to its versatile platform enabling users to easily create and manage their own blockchain projects.
42. **Aeternity** is **infrastructure**, as it provides a blockchain platform designed for high-bandwidth transacting, smart contracts and decentralized applications.
43. **Icon** is **infrastructure**, as it focuses on creating an ecosystem of interconnected blockchains for various sectors.
44. **Holochain** is **infrastructure**, representing a post-blockchain technology that enables decentralized app development without the scalability issues of traditional blockchains.
45. **Harmony** is **infrastructure**, with its focus on providing a scalable and efficient platform for the development and operation of dApps.
46. **Lisk** is **infrastructure**, as it offers a platform for developers to create and deploy decentralized applications in a user-friendly environment.

## Application / Infrastructure

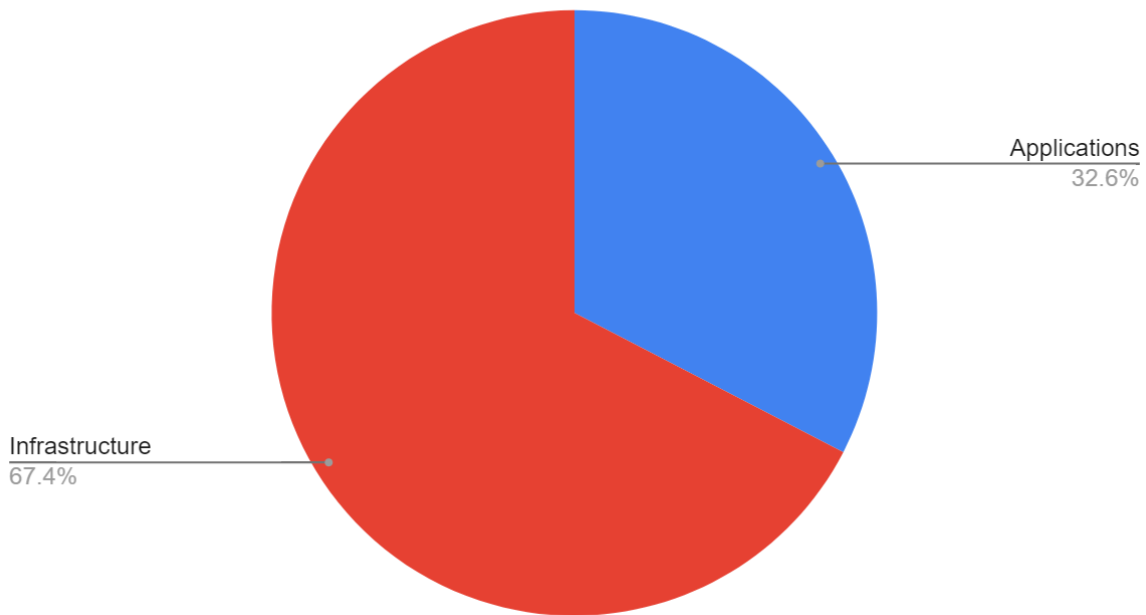


*Image 8: Application / Infrastructure*

The analysis conducted for this paper reveals a predominant focus on infrastructure, with 67.4% of the surveyed BCTs dedicated to establishing robust platforms essential for the broader adoption and functionality of blockchain technologies. This foundational emphasis not only supports the digital transformation across various sectors but also serves as a critical backbone for the development of specific blockchain applications, encompassing the remaining 32.6%.

Infrastructure-oriented BCTs are vital in creating a decentralized framework that supports a myriad of applications. These platforms, characterized by their scalability, security and efficiency, offer a versatile foundation for the deployment of decentralized applications (dApps). Such infrastructure projects are pivotal for the blockchain ecosystem, providing the essential components necessary for transaction processing, data verification and network security. This emphasis on infrastructure is indicative of a strategic approach within the blockchain community to ensure the technology's long-term sustainability and scalability.

Conversely, application-focused BCTs leverage the robustness of blockchain infrastructure to deliver targeted solutions aimed at resolving industry-specific challenges. These applications, which range from financial services to supply chain management and beyond, highlight the technology's capability to simplify processes, enhance transparency and secure data exchange. The development of applications on top of established infrastructures exemplifies the practical application of blockchain technology in solving real-world problems, thereby driving its adoption across various domains.

The clear division between infrastructure and application BCTs highlights an in-depth analysis of the blockchain ecosystem's development. Infrastructure solutions provide the essential foundation for a secure and scalable blockchain environment, while applications directly utilize this technology to meet specific challenges. The balance between foundational support and tangible application is vital for the ongoing expansion and significance of blockchain technologies.

The strategic focus on infrastructure development within the BCT landscape reflects a broader trend towards building a solid foundation for the future of decentralized technologies. By prioritizing infrastructure, the blockchain sector is positioning itself to support a wide array of applications, thereby facilitating innovation and ensuring the technology's adaptability to future demands. As such, the analysis of the distribution between infrastructure and application BCTs not

only highlights the current state of blockchain development but also provides insights into the strategic directions being pursued within the field.

### SDGs for applications/infrastructures

#### SDGs for Applications/Infrastructures

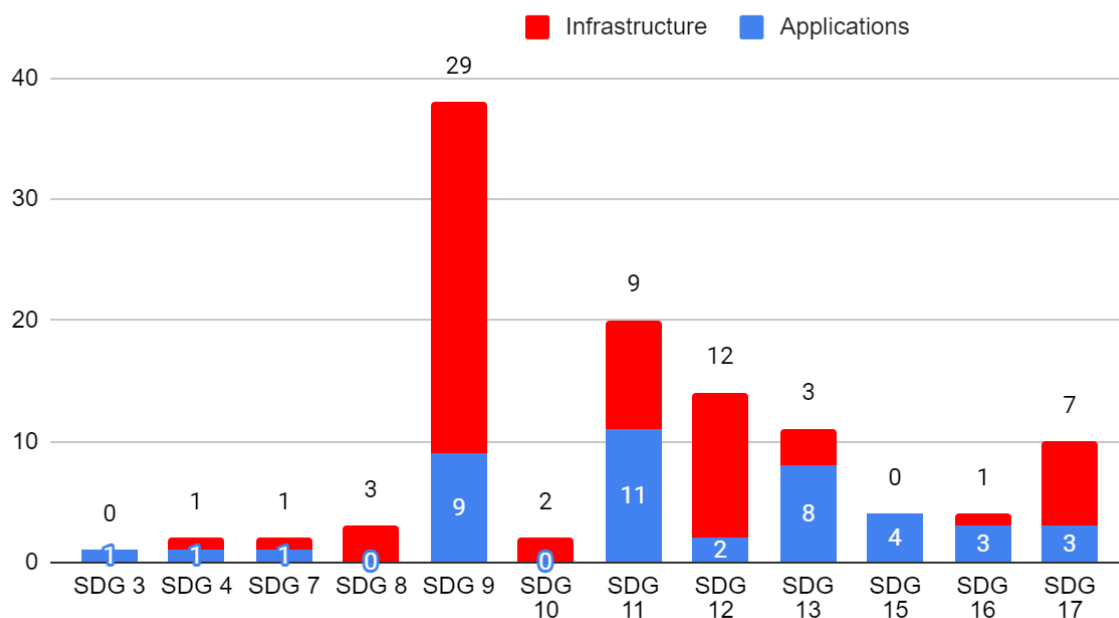


Image 9: SDGs for Applications/Infrastructures

Table 5: Applications/Infrastructure SDGs

|         | Applications | Infrastructures |
|---------|--------------|-----------------|
| SDG 3:  | 1            | 0               |
| SDG 4:  | 1            | 1               |
| SDG 7:  | 1            | 1               |
| SDG 8:  | 0            | 3               |
| SDG 9:  | 9            | 29              |
| SDG 10: | 0            | 2               |
| SDG 11: | 11           | 9               |
| SDG 12: | 2            | 12              |

|         |   |   |
|---------|---|---|
| SDG 13: | 8 | 3 |
| SDG 15: | 4 | 0 |
| SDG 16: | 3 | 1 |
| SDG 17: | 3 | 7 |

### 5.7. Application level

Table 6: Application level

| #  | <u>Name of BCT solution</u>       | <u>Application level</u> |
|----|-----------------------------------|--------------------------|
| 1  | Universa                          | Regional                 |
| 2  | Responsible Box                   | Municipal                |
| 3  | DOVU                              | Regional                 |
| 4  | SmartKey                          | Regional                 |
| 5  | Observatory of Urban Mobility     | Municipal                |
| 6  | Personal Health Record OS (phrOS) | Municipal                |
| 7  | IoMob                             | Regional                 |
| 8  | XignIn City                       | Municipal                |
| 9  | Changers CO2 Fit App              | Municipal                |
| 10 | DataBroker DAO                    | Municipal                |
| 11 | Smart City Database Platform      | Regional                 |
| 12 | GlobalTech.City                   | International            |
| 13 | Vizsafe                           | Regional                 |
| 14 | DECODE                            | International            |
| 15 | Councilbox OVAC                   | Municipal                |
| 16 | SDG Assessment App                | Regional                 |
| 17 | Hedera                            | Organisational           |
| 18 | Hyperledger Fabric                | Enterprise               |
| 19 | Corda by R3                       | Enterprise               |
| 20 | Quorum                            | Enterprise               |
| 21 | EOS.IO                            | Global                   |
| 22 | Tezos                             | Global                   |
| 23 | NEO                               | Global                   |
| 24 | Algorand                          | Global                   |
| 25 | VeChain                           | Global                   |
| 26 | Ardor                             | Global                   |
| 27 | Stellar                           | Global                   |

## Ανασκόπηση εφαρμογών και υποδομών για την τεχνολογία blockchain

|    |                            |            |
|----|----------------------------|------------|
| 28 | IOTA                       | Global     |
| 29 | Chainlink                  | Global     |
| 30 | Polkadot                   | Global     |
| 31 | Avalanche                  | Global     |
| 32 | Solana                     | Global     |
| 33 | Corda                      | Enterprise |
| 34 | Zilliqa                    | Global     |
| 35 | Cardano                    | Global     |
| 36 | Cosmos                     | Global     |
| 37 | Elrond                     | Global     |
| 38 | Qtum                       | Global     |
| 39 | NEM (New Economy Movement) | Global     |
| 40 | Ontology                   | Global     |
| 41 | Waves                      | Global     |
| 42 | Aeternity                  | Global     |
| 43 | Icon (ICX)                 | Global     |
| 44 | Holochain                  | Community  |
| 45 | Harmony (ONE)              | Global     |
| 46 | Lisk                       | Global     |

### Application level statistics

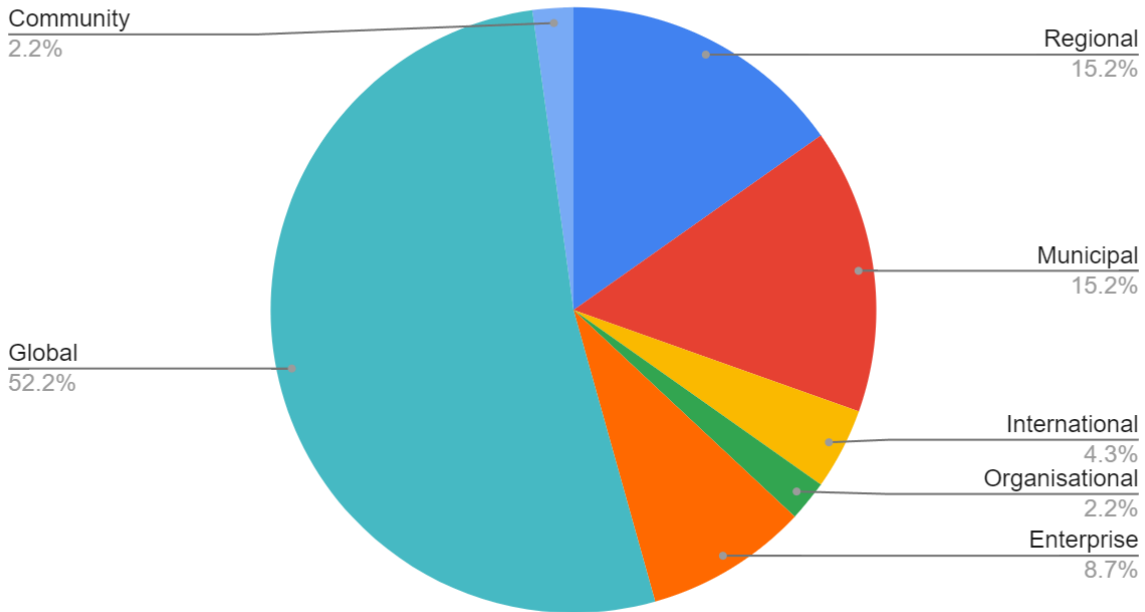


Image 10: Application level statistics

- Global : 52.2%
- Regional : 15.2%
- Municipal : 15.2%
- Enterprise : 8.7%
- International : 4.3%
- Organizational : 2.2%
- Community : 2.2%

The “application level” of blockchain projects in the dataset shows a dominant preference for global applications, at 52.2%, indicating a focus on solutions with worldwide reach and impact. This prominence of global applications aligns with the foundational concept of blockchain technology as inherently borderless, designed to transcend geographical and jurisdictional boundaries. Regional and municipal applications each account for 15.2%, reflecting the technology's relevance in addressing more localized needs. Enterprise-level applications, at 8.7%, demonstrate blockchain's utility in business contexts, while international applications, at 4.3%, suggest its role in cross-border issues. Organizational and community levels, each at 2.2%, highlight its potential in smaller, more specific contexts. This distribution showcases blockchain's versatility across various scales and domains.

### 5.8. Additional characteristics

Table 7: Additional characteristics

| # | Cost                                                                      | Countries |
|---|---------------------------------------------------------------------------|-----------|
| 1 | "enormously low"<br>The UTN tokens are used to pay fees for network usage | BRICS     |

## Ανασκόπηση εφαρμογών και υποδομών για την τεχνολογία blockchain

|    |                                                                                                                                                                                                                       |                                                         |
|----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
|    | and these fees are then split between the nodes using the network and the Universa Foundation.                                                                                                                        |                                                         |
| 2  | N/A                                                                                                                                                                                                                   | Italy                                                   |
| 3  | The price of one DOV token                                                                                                                                                                                            | United Kingdom                                          |
| 4  | The price of the SKEY token                                                                                                                                                                                           | Poland                                                  |
| 5  | €300.000,00                                                                                                                                                                                                           | Brazil                                                  |
|    | phrOS Subscription Fee:<br>1. Service fee + 3 years subscription fee - US\$ 250,000                                                                                                                                   |                                                         |
| 6  | 2. Yearly subscription fee 4th year onward- US\$ 50,000                                                                                                                                                               | Taiwan                                                  |
| 7  | Minimum platform fees, no upfront costs and fees may even be recovered via active use of the protocol.                                                                                                                | Spain , Estonia                                         |
| 8  | The development costs of 5.2 Million Euro for XignIn City are paid by the German state North Rhine Westphalia.<br>Cities, states and countries will have to pay only a few cents per user per year to use the system. | Germany                                                 |
| 9  | annual system costs between 20k and 80k Euro Rewards according to the budget 10-20% of the system costs.                                                                                                              | Germany                                                 |
| 10 | DTX tokens                                                                                                                                                                                                            | Belgium, United Arab Emirates                           |
| 11 | 20.000,00                                                                                                                                                                                                             | Netherlands                                             |
| 12 | N/A                                                                                                                                                                                                                   | Netherlands                                             |
| 13 | N/A                                                                                                                                                                                                                   | USA, Mexico, UAE                                        |
| 14 | N/A                                                                                                                                                                                                                   | Netherlands                                             |
| 15 | N/A                                                                                                                                                                                                                   | Spain                                                   |
| 16 | Costs are as follows: Labour: \$20500 R&D , App Technology Deployment: \$47000<br>Advertising: \$3000 Marketing: \$4500 , Estimated Total Project Costs: \$100000                                                     | Undisclosed                                             |
| 17 | average cost : \$0.001 per transaction                                                                                                                                                                                | Global                                                  |
| 18 | Varies depending on implementation, open-source and free to use.                                                                                                                                                      | Global (used by enterprises worldwide)                  |
| 19 | Varies, enterprise version is paid, open-source version available.                                                                                                                                                    | Global                                                  |
| 20 | Free and open-source, costs associated with implementation and maintenance.                                                                                                                                           | Global                                                  |
| 21 | Low transaction costs due to efficient resource management                                                                                                                                                            | Global (not regulated by a single government entity)    |
| 22 | Transaction fees in native currency XTZ                                                                                                                                                                               | Global (decentralized, not governed by a single entity) |
| 23 | Transaction fees in NEO tokens                                                                                                                                                                                        | Global (especially noted in the Chinese market)         |
| 24 | Minimal transaction costs                                                                                                                                                                                             | Global (not regulated by a single government entity)    |

|    |                                                                                                                                                                        |                                                             |
|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
| 25 | Transaction fees in VET and VTHO tokens                                                                                                                                | Global (with a strong presence in Europe, Asia and America) |
| 26 | Transaction fees paid in ARDR tokens. Transaction costs vary depending on the child chain but are generally low due to the efficiency of the Proof of Stake mechanism. | Switzerland                                                 |
| 27 | Low transaction fees (fractions of a cent), making it highly efficient for international transfers and micropayments.                                                  | USA                                                         |
| 28 | Zero transaction fees, which is a key feature of IOTA, making it attractive for microtransactions in the IoT ecosystem.                                                | Germany                                                     |
| 29 | Transaction fees paid in LINK tokens                                                                                                                                   | Global                                                      |
| 30 | The cost to use Polkadot varies based on transaction complexity and network demand. It uses a dynamic fee system.                                                      | USA, the European Union, Switzerland and internationally    |
| 31 | he cost of transactions on Avalanche varies based on network load and transaction complexity. It uses a fee model to ensure network security and performance.          | USA                                                         |
| 32 | Transaction costs on Solana are significantly lower compared to many other blockchains, offering an economical alternative for high-frequency transactions.            | USA                                                         |
| 33 | Being a permissioned blockchain, costs are associated with network participation and infrastructure but are typically lower compared to public blockchains.            | USA                                                         |
| 34 | Transaction costs on Zilliqa are relatively low due to its high-efficiency consensus mechanism and sharding technology.                                                | Singapore                                                   |
| 35 | Transaction costs on Cardano are generally lower compared to major proof-of-work blockchains, making it more economical for users.                                     | Switzerland                                                 |
| 36 | Varies based on the specific blockchain within the Cosmos network, but generally, it offers reduced transaction fees due to its efficient consensus mechanism.         | Global                                                      |
| 37 | Low transaction fees, attributed to its efficient consensus mechanism and high throughput capabilities.                                                                | Global                                                      |
| 38 | The transaction costs on Qtum are relatively low, benefiting from the efficiency of the PoS mechanism and optimized network design.                                    | Global                                                      |
| 39 | Transaction costs are relatively low and the PoI mechanism ensures that active participants can benefit from lower fees.                                               | Singapore                                                   |
| 40 | Transaction costs are low due to efficient consensus mechanisms and network design.                                                                                    | Global                                                      |
| 41 | Transaction costs on Waves are relatively low and the LPoS mechanism allows for lightweight and efficient network security.                                            | Germany                                                     |

|    |                                                                                                                                                                                    |             |
|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 42 | Transaction costs are competitive, benefiting from the efficiency of its hybrid consensus mechanism and off-chain scaling solutions.                                               | Undisclosed |
| 43 | Transaction costs on Icon are moderate, aiming to balance network sustainability with user accessibility.                                                                          | Global      |
| 44 | Very low, as it does not require traditional mining or staking mechanisms.<br>The architecture of Holochain is designed to reduce transaction and operational costs significantly. | Global      |
| 45 | The transaction costs are low, with a focus on maintaining affordability while ensuring network security and sustainability.                                                       | Global      |
| 46 | The transaction fees on Lisk are relatively low, encouraging developers and users to engage with the platform without significant financial barriers.                              | Global      |

### Countries statistics

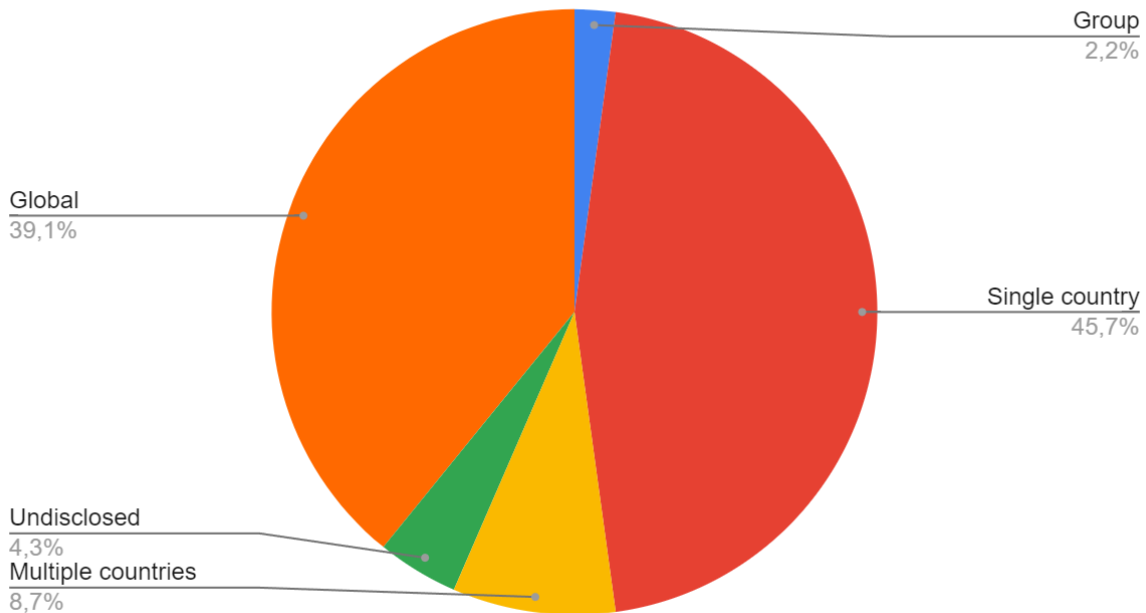


Image 11: Countries statistics

- Single country: 45.7%
- Global: 39.1%
- Multiple countries: 8.7%
- Undisclosed: 4.3%
- Group of countries: 2.2%

A significant 45.7% of blockchain technologies are applied within a single country, highlighting the tailored approach to meeting localized regulatory, economic, and societal needs. Global

applications account for 39.1%, emphasizing blockchain's inherent nature of decentralization and its capacity to serve worldwide solutions beyond borders. The application in multiple countries (8.7%) and by a group of countries (2.2%) indicates a growing trend towards regional and international collaboration, leveraging blockchain for common challenges. The 4.3% undisclosed, suggests confidentiality or lack of information due to early stages of development, so projects that are not providing enough public information for their project, either because they choose not to or because they don't have enough yet to share.

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### **Bridging the Gap: Global Potential vs. Local Implementation of BCT**

There is a notable discrepancy between the “application level” statistical results and the “countries” statistical results. Specifically, while 52.2% of BCTs are identified as having a global “application level”, only 39.1% are categorized as being implemented globally according to the “Countries” perspective column. This disparity suggests that, although many BCTs possess inherent capabilities for worldwide application, their current usage is predominantly within specific countries for targeted purposes.

The inherent scalability of blockchain technologies allows for global applications; however, practical deployment often starts on a smaller scale due to regulatory, economic, and logistical considerations. Implementing blockchain solutions across borders involves navigating diverse regulatory environments, which can pose significant challenges. Furthermore, many blockchain projects are initiated to address specific local or regional issues before they are scaled up to a global level.

## **6. Discussion**

### **6.1. Research implications**

This paper's exploration of blockchain technology (BCT) significantly advances the field, offering a foundational framework for future research. Through the comprehensive analysis of BCT applications and infrastructure, it defines a clear path for investigating the versatile impacts of blockchain across various sectors. The implications for further research are multiple:

1. **Framework for Innovation:** By categorizing blockchain solutions and identifying their unique attributes, this paper serves as a critical resource for researchers aiming to innovate within the blockchain ecosystem. The detailed dataset of BCTs provides a basis for comparative studies, fostering innovation in developing new blockchain applications and infrastructure.
2. **Cross-sector Impact Analysis:** The paper's analysis across different domains highlights blockchain's potential to revolutionize industries by addressing key challenges and unlocking new opportunities. Future research can leverage this cross-sector perspective to conduct in-depth studies on blockchain's impact on specific industries, focusing on efficiency, security and scalability improvements.
3. **Sustainable Development Goals (SDGs):** Emphasizing the importance of SDGs, as consistently highlighted throughout this paper, the connection between blockchain technology and SDGs presented here outlines a promising area for research. Future studies can delve into how blockchain can contribute to achieving SDGs, focusing on environmental sustainability, economic growth and social inclusivity, highlighting the pivotal role SDGs played in the research and analysis conducted in this paper.
4. **Technological Evolution and Adaptation:** The examination of blockchain generations reveals a technology in flux, rapidly evolving to meet the demands of the digital age. Further research can delve into the evolutionary trajectory of blockchain, predicting future developments and exploring how blockchain can adapt to new digital challenges.
5. **Policy and Governance:** The paper highlights the importance of governance in BCTs. Future research could explore the regulatory implications of BCTs, developing frameworks for governance that ensure transparency, security and equitable access to blockchain technologies.

6. **Economic and Financial Analysis:** By highlighting the economic aspects of blockchain applications, the paper opens avenues for research into the financial viability and cost-effectiveness of blockchain solutions. Such studies could provide valuable insights for businesses and policymakers regarding the adoption and investment in blockchain technologies.
7. **Technological Readiness and Infrastructure:** The discussion on Technology Readiness Levels (TRLs) and infrastructure requirements for blockchain implementations provides a guideline for assessing the maturity of blockchain solutions. Future research could focus on the development and validation of methodologies to evaluate the readiness of blockchain technologies for widespread adoption.
8. **Collaborative Research Across Fields:** This paper makes it clear that research on blockchain touches many areas like computer science, economics and law. It suggests working together across different fields to truly understand and use blockchain's full potential.

In conclusion, this paper not only enhances our understanding of blockchain's current state but also sets the stage for diverse research trajectories. It invites scholars to build upon its findings, fostering a deeper exploration of blockchain's capabilities, challenges and its transformative potential across the globe.

## 6.2. Practitioner/government implication

This paper's findings have significant implications for public organizations, guiding the integration of blockchain technology (BCT) in public services and policy-making. For practitioners and government bodies:

- **Policy Development:** The research emphasizes the need for informed policy-making that supports blockchain innovation while addressing regulatory challenges. It offers a knowledge base for developing policies that foster BCT adoption in public services, ensuring security, transparency and efficiency.
- **Public Service Innovation:** By showcasing blockchain's potential across various sectors, the paper encourages public organizations to explore blockchain solutions for improving service delivery. This could include enhancing data integrity in public records, simplifying processes and facilitating secure transactions.
- **SDGs Alignment:** Recognizing the role of BCTs in advancing Sustainable Development Goals, public organizations can leverage blockchain to address social, economic and environmental challenges, aligning technology initiatives with global sustainability efforts.
- **Intersectoral Collaboration:** The paper suggests working together among government, academia and businesses to explore and apply blockchain solutions, enhancing public services through shared knowledge and innovation.

In essence, this paper not only enlightens public sector practitioners about the transformative potential of blockchain but also serves as a call to action for leveraging BCT to enhance public service delivery and contribute to societal goals.

## 7. Conclusions

This paper has extensively reviewed the varied BCTs, both applications and infrastructures, highlighting their significant impact across various sectors. Like this paper explores in depth, blockchain's decentralized nature offers unparalleled security, transparency and efficiency, particularly in financial transactions, healthcare and digital identity verification, while at the same time having an unprecedented impact across multiple other aspects of society and the everyday lives of people. Its capacity to enable trustless transactions and reduce intermediaries significantly transforms operational models, fostering greater economic efficiency and innovation.

Despite its potential, blockchain technology faces several challenges that must be addressed to reach its full potential. Scalability remains a primary concern, as current blockchain solutions struggle to manage high volumes of transactions swiftly. Additionally, the environmental impact of blockchain, especially proof-of-work (PoW) consensus mechanisms, raises sustainability concerns. The regulatory landscape also presents hurdles, with varying global standards complicating the technology's adoption and implementation.

Looking forward, the integration of blockchain with emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT) and quantum computing signals the beginning of a new phase in digital transformation. These integrations could unlock new applications, enhance system efficiencies and reduce existing limitations, particularly in scalability and sustainability. For instance, the development of more energy-efficient consensus mechanisms, such as proof-of-stake (PoS) could address critical environmental and security challenges.

The evolving regulatory environment will play a crucial role in shaping blockchain's future. Creating regulations that balance innovation with consumer protection could accelerate adoption, while fostering an ecosystem targeted to research and development is essential for advancing blockchain technology.

In conclusion, blockchain technology stands at the edge of revolutionizing our digital landscape. By addressing its current challenges and leveraging collaborations with other technological advancements, blockchain could significantly contribute to a more transparent, secure and efficient digital future. Continued collaboration among technologists, policymakers and industry stakeholders is imperative to navigate the complexities of this evolving field and unlock the transformative potential of blockchain technology.

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