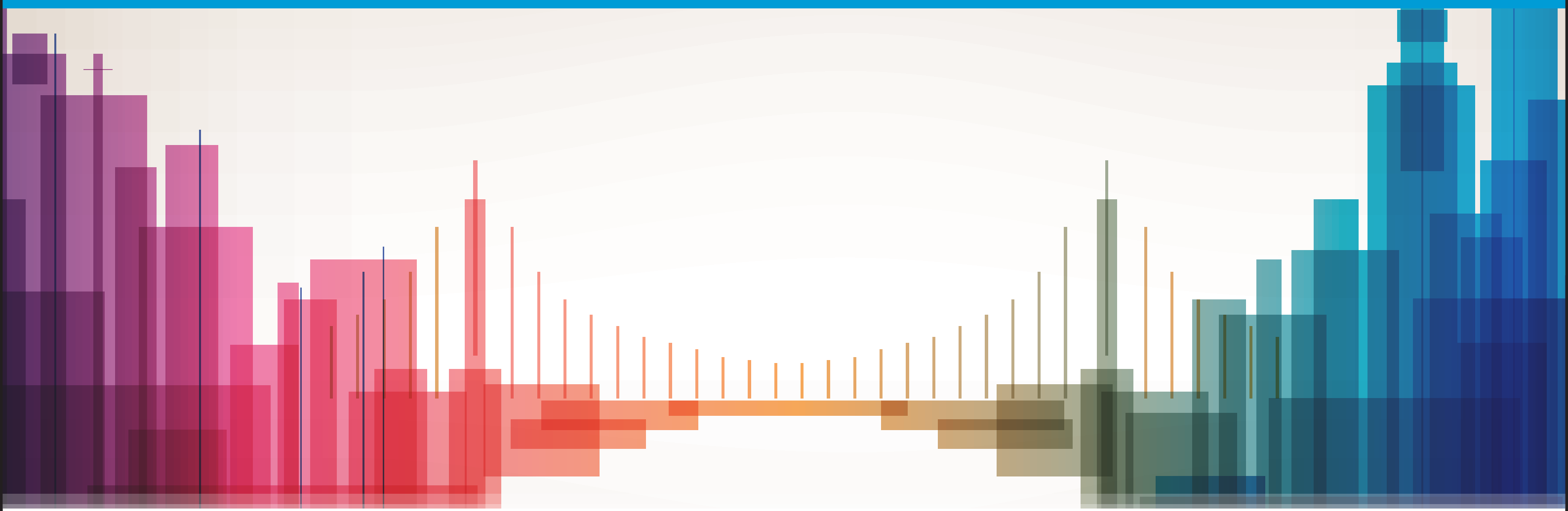
United 4 Smart Sustainable Cities

Blockchain for smart sustainable cities



Convention on Biological Diversity

United Nations ECLAC

Food and Agriculture Organization of the United Nations

ITU

UNDP Empowered lives. Resilient nations.

United Nations Economic Commission for Africa

UNECE

UNESCO United Nations Educational, Scientific and Cultural Organization

UN environment programme

UNEP Finance Initiative

United Nations Framework Convention on Climate Change

UN-HABITAT FOR A BETTER URBAN FUTURE

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UN Women

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Foreword

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Disclaimer

The opinions expressed in this publication are those of the authors and do not necessarily represent the views of their respective organizations or U4SSC members. In line with the U4SSC principles, this report does not promote the adoption and use of blockchain technology. It advocates for policies encouraging responsible use of ICTs that contribute to the economic, environmental and social sustainability as well as the advancement of the 2030 Agenda for Sustainable Development. The study conducted in this report is based on extensive literature review, interviews and voluntary written contributions from stakeholders.

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Executive summary

As the world is exploring new methods to face pre-existing urban challenges, the concept of "smart cities" can offer guidance on making cities more resilient and responsive to crises. In the current scenario, global crises and their human and economic impact have also provided a new impetus for the uptake of digital tools and emerging technologies.

The coupling of artificial intelligence (AI) and Internet of things (IoT) in the urban ecosystem has brought about an unprecedented demand for ensuring the transparency, security and privacy of data. These frontier technologies, combined with blockchain, have become promising tools capable of addressing global urban expectations. To this end, blockchain has found a wide spectrum of applications within the cities, encompassing a diversity of public services from health and finance to education and energy, among others. This makes blockchain a critical technology in the effort of making cities more sustainable by addressing several targets stipulated in the Sustainable Development Goals (SDGs), including Sustainable Development Goal 11 on Sustainable Cities and Communities, for the establishment of smart cities.

This report delves into the current advancements and applications of blockchain in smart cities, across the various verticals. It further explores the role played by blockchain technologies in designing an efficient, secure and scalable distributed architecture to address the significant challenges on interoperability protocols, security and privacy, data collection and sharing, data analytics, and latency within smart cities. As a stepping-stone for the penetration of blockchain technologies into the global smart city agenda, this report underscores a series of use-cases highlighting the adoption of this technology into various spheres. Building on the analysis of the use-cases, the report also identifies promising areas for future research in this domain.

Based on the analysis of the use-cases in terms of the challenges, opportunities and lessons learned, this report demonstrates the complexity of the blockchain for cities and proposes the 4S (Situation, Sustainability, Smartness, and Suitability) framework by highlighting the critical dimensions and patterns for the application of blockchain in smart cities.

Blockchain-based smart city initiatives are complex and compel the involvement of multiple stakeholders, and require different types of expertise. For further progress on the blockchain front, building an ecosystem to share knowledge and expertise as well as developing capabilities is critical. It is also essential to enable new opportunities for collaboration that will require defining an adequate governance model, aligning all the stakeholders to a shared vision for the city, and creating an appropriate regulatory framework that provides flexibility for future innovation. Accordingly, the report concludes with a sequence of research-driven policy recommendations that should be incorporated by the urban stakeholders and decision-makers for embracing the required frameworks and translating them into action plans to facilitate blockchain use within the realm of smart cities.

It is expected that low- and middle- income countries will face significant challenges related to creating a conducive ecosystem for the appropriate use of blockchain technologies, which requires substantial investment in digital infrastructure as well as technology transfer. Efforts in this direction are expected to enable the development of initiatives using blockchain that could support cities as well as rural areas and communities, to face economic, social and environmental challenges (in line with the Sustainable Development Goals).

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List of abbreviations

AC	Active Citizen
AI	Artificial intelligence
API	Application programming interface
B4C	Blockchain for cities
CJIB	Dutch Central Judicial Debt Collection Agency
COVID-19	Coronavirus pandemic of 2019
DDDC	Digital Democracy and Data Commons
DLT	Distributed ledger technology
FG-AI4EE	Focus Group on Environmental Efficiency for Artificial Intelligence and other Emerging Technologies
FG-SSC	Focus Group on Smart Sustainable Cities
GDPR	General Data Protection Regulation
ICO	Initial coin offering
ICTs	Information and communication technologies
IoT	Internet of things
IT	Information technology
ITU	International Telecommunication Union
ITU-T SG20	ITU-T Study Group on Internet of things and smart cities and communities
NAPR	National Agency of the Public Registry, Georgia
NPM	New Public Management
P2P	Peer-to-peer
PBFT	Practical Byzantine Fault Tolerance
PoA	Proof of Authority
PoET	Proof of Elapsed Time
PoS	Proof of stake
PoW	Proof of Work
SDGs	Sustainable Development Goals
SSC	Smart Sustainable City
UI	User interface
UNU-EGOV	United Nations University Operating Unit on Policy-Driven Electronic Governance
UX	User experience

1. Introduction

1.1 Context and background

Many cities around the world are facing acute challenges in managing rapid urbanization. These challenges range from ensuring adequate housing and infrastructure to support the growing population in overcoming the environmental impact of urban sprawl, and reducing vulnerability to disasters (natural, man-made or epidemiologic). Furthermore, cities as well as communities have faced substantial challenges including socio-economic inequality, poverty, unemployment, poor environmental conditions and high levels of greenhouse gas emissions. These challenges persist and are expected to be magnified by the impact of the Coronavirus disease 2019 (COVID-19) pandemic. Estimates show that two-thirds of the world's population will live in cities by the year 2050, up from 55 per cent today.[1] As a result of the increase in population coupled with the expansion of production and manufacturing, cities will consume significant resources and require more efficient and more sustainable services. If the provision of such services to cities is not made in a controlled manner, the urban areas and surrounding environments will suffer, hampering the potential of cities to drive growth, innovation and prosperity for themselves and the country at large.

The potential for exacerbation of the problems affecting cities makes them significant vectors for actions to tackle urgent challenges such as poverty, inequality, pollution, mitigation and adaption to climate change. The Sustainable Development Goals (SDGs) of the United Nations aim to address these challenges. The density and economic concentration of cities mean that they need to function effectively for all the sustainable development goals to be met since they are sites of concentrated human activity and residence. To this end, Sustainable Development Goal 11, to make cities and human settlements inclusive, safe, resilient and sustainable, reflects the main targets related to overcoming the aforementioned urban challenges.

A centrepiece of efforts to reach this goal is imperative to make our cities more sustainable through better utilization of technology. Within the concept of smart cities, solutions are to be found to make cities and communities more efficient, more technologically advanced, greener, and more socially inclusive. In this context, one of the key definitions for Smart sustainable cities (SSC) developed by the International Telecommunication Union (ITU) is as follows:[2]

> *"[...]an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental, as well as cultural aspects.." (Recommendation ITU-T Y.4900).*

ICTs and emerging technologies promise effective decision-making tools and opportunities to improve efficiency across services and sectors. The application of new technologies for service delivery and infrastructure development in smart cities will generate information for the planning, monitoring and control of resource consumption, making resources available in these areas and to the sections of the population with the greatest need.

For example, smart systems will facilitate better management of recycling and the overall disposal of waste, thus ensuring sustainability. In general, from the optimization of transport networks and resource management, through intelligent platforms for capturing and analyzing environmental and behavioural data, the development of smart cities infrastructure can enable better strategies for sustainable urban development and help to create an appropriate, safe and sustainable urban ecosystem.

However, there are many challenges associated with the implementation of a smart city. In addition to ICT security issues, smart cities are primarily concerned with the question of how automation, as well as communication can be handled between people and ICT devices. Technical, social and regulatory challenges must be considered. In this scenario, technology is only part of the puzzle; the main challenge lies in demonstrating and uncovering innovative business ideas, regulatory frameworks, governance arrangements, partnerships, institutions, processes, and incentives for the benefit of all.

With the adoption of emerging technologies like the Internet of things (IoT) for facilitating smart city transitions, there is a surge in the number of sensors and devices within the smart city ecosystem. With the traction gained by IoT within smart cities, there is an increase in the generation of data, which can be leveraged by artificial intelligence (AI) for active training and the operation of real-time smart machines to automate the provision of certain services. However, the trade-off between data transparency (and privacy) and the utility of AI in supporting Big data analytics, is the foremost concern for smart city stakeholders. In this context, blockchain technology is increasingly seen as a tool for boosting data transparency and traceability in smart cities. As a decentralized IT infrastructure, blockchain technology can serve as a suitable means to manage the growing networks emanating from smart cities in terms of monitoring supply chains, executing and validating data trails along with ensuring authenticity and integrity of data. Blockchain technology through secure and transparent infrastructure promises an immutable and traceable exchange of sensitive data and property values, not only between people but also between machines.

As a result, blockchain technology is increasingly catching the attention of companies, as well as public institutions. Cities can use blockchain to create a secure and shared ledger to manage real-time data in transportation, energy and utilities. The implementation of the technology can help cities to streamline how they interface with citizens, reduce resource consumption, and share public data with authorized third parties. Furthermore, the infrastructure of the future will require high-security standards to reliably guarantee the required degree of networking, automation, decentralization and participation. These requirements are aligned with the SDG 11: “Make cities and human settlements inclusive, safe, resilient and sustainable”.

The benefits of blockchain for government and public services and information about potential application areas and use-cases can be found in relevant literature, including academic papers and other reports.[3] More than 200 initiatives relating to blockchain for governments can be identified in over 45 countries. Many cities around the world are planning, developing or launching blockchain-based applications. These projects are undertaken mostly at the local level as part of the smart cities initiative’s overall efforts towards shaping the cities’ futures. Nonetheless, the early stage of the blockchain development and the lack of in-depth, use-cases analysis make it challenging, considering the different requirements of each solution, the varying characteristics of blockchain technology and the distinct design approach of each use-case in addition to the limitations and uncertainties. All these aspects create a gap between the existing knowledge on blockchain application in the city context and the actions of the urban planners and policymakers.

1.2 Purpose and objectives

The blockchain for cities (B4C) report is part of the efforts of the United for Smart Sustainable Cities (U4SSC) initiative to support long-term strategies for smart and sustainable cities. The primary purpose of this report is to understand the potential for blockchain as a central technology for initiatives aimed at making cities smarter and more sustainable. The objective is to better understand the effectiveness and relevance of blockchain technology in the context of the city. It explores and analyzes the potential, the transformative effect, the benefits and the challenges of blockchain technology for cities and proposes a framework defining the most important dimensions to be considered for blockchain applications, in accordance with the contextual and cultural specificities of each city.

This report intends to provide a better understanding of the blockchain technology, as well as underscore policy recommendations to guide local and city managers, decision-makers and policymakers on key considerations for the application of blockchain technologies in their smart city initiatives. In alignment with the principles of the U4SSC initiative, this deliverable does not intend to promote the adoption and use of blockchain technology. Conversely, it advocates for policies encouraging responsible use of ICTs that contribute to the economic, environmental and social sustainability as well as the advancement of the 2030 Agenda for Sustainable Development.

1.3 Approach

To achieve the purpose of this study, the approach adopted for this report was based on extensive desk research and document analysis, interviews as well as on the combining of qualitative and quantitative data-collection methods. This study commenced with the collection of data from city and municipality managers and officials through a questionnaire. The purpose of this survey was to better comprehend and evaluate the level of understanding as well as the level of interest in blockchain technology at the local government level. The results of the survey guide the definition of the purpose and focus of the study. The analysis demonstrated the interest of the cities towards blockchain technology (77%), limited understanding and knowledge of blockchain (82%), an essential need of exemplar use-cases and application of the technology in the context of public service and at the smart city level (68%) as well as the need to identify the benefits and risks of blockchain (61%).

In addition to examining the responses to the questionnaire, an extensive document and literature analysis on blockchain technology was conducted. This phase was supplemented with interviews of experts in the field (including practitioners, academics and developers) to clearly understand the complexity of the technology and its characteristics, properties, benefits and challenges, specifically in the context of local public service and city initiatives. Following this, different use-cases were collected, of which 13 were selected. This phase allowed the development of a preliminary framework highlighting the need to better understand: the use and adoption of blockchain in the city and settlement context; the urban and local challenges addressed by the use of blockchain technology; and the need to identify the potential benefits and challenges related to the development of blockchain solutions for cities. These aspects lay the foundation for analyzing the readiness through the definition of the solution requirements, the resources and capabilities needed for B4C, as well as addressing compliance with the sustainability dimension and the relevant SDG.

As a part of the last phase, the aforementioned elements were incorporated into a questionnaire that was sent to different experts to complete and analyze the use-cases, collect feedback and validate the critical elements to consider adopting blockchain for smart, sustainable cities. The study was furthered with the analysis of 20+ decision-making models and frameworks for blockchain adoption that supported and framed the efforts to provide clear information and directions for informed decision-making and identifying the situation and the type of blockchain technology that could be considered as the most appropriate. Based on these analyzes and the findings, a blockchain for city framework was proposed, along with key considerations for the effective adoption of blockchain technology for smart city development. Finally, the findings were reflected in research-driven policy recommendations to guide city leaders and organizations around the world. The recommendations provided on the use of blockchain for smart and sustainable cities and communities aim to be useful and appropriate for smart cities in industrialized countries, as well as cities in developing countries. The framework development, the policy recommendations and the implementation key considerations also take resources, capabilities, ethics and regulatory aspects into account along with the smartness and sustainability factors.

The first section of this report highlights the scope of the study on blockchain technology for cities, along with the approach adopted for the analyzes. Section 2 explores the general characteristics of blockchain technology and section 3 presents information about smart sustainable cities in the international context. Section 4 describes the blockchain for cities use-cases and section 5 details the cross-case analysis and framework development. Finally, section 6 highlights the key considerations and policy recommendations for urban stakeholders who which to incorporate blockchain technology for smart city transitions.

2. Unfolding blockchain technology

2.1 Introduction to blockchain technology

Blockchain is an open and shared distributed ledger technology (DLT), which can record transactions between two parties efficiently, permanently and in a verifiable way.[4] It consists of a shared digital data storage, replicated and synchronized across multiple devices in a network. The main objective of DLT is to establish trust, accountability and transparency, with no reliance on a single source of authority or in environments where there is a lack of trust between actors. It also promotes decentralization and data integrity.

Within the smart city ecosystem, the rise of blockchain technology as a transparent and responsible mechanism for protecting data is paving the way for resolving serious data privacy, security and integrity challenges.

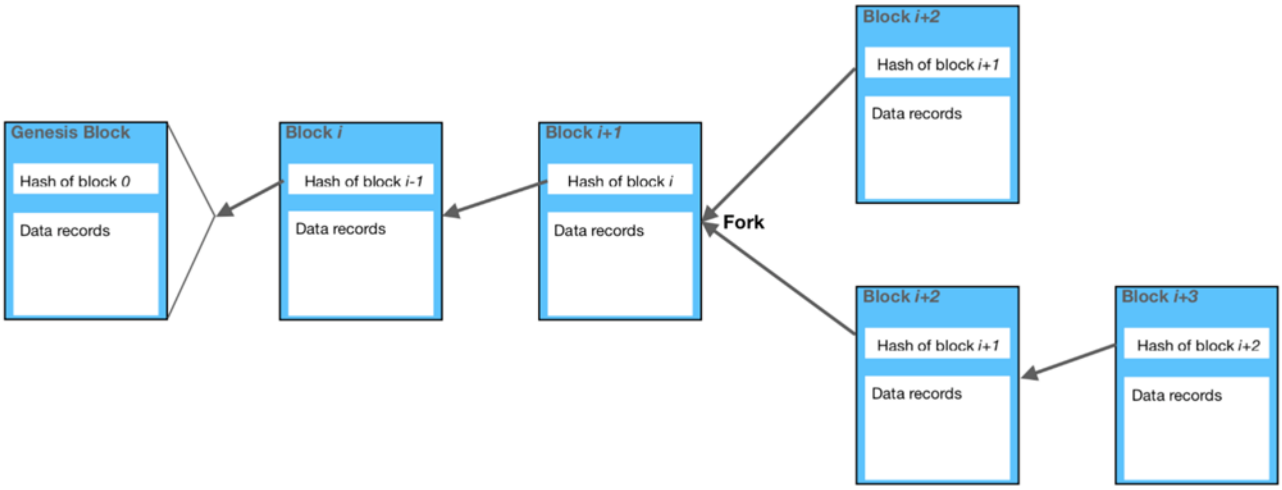
Furthermore, blockchain is increasingly being utilized in different smart city applications relating to data access, control and sharing for the management of health records, energy and finance. Based on the principles of its operation, various aspects related to blockchain including its taxonomies are explored in this section. (For more details on the applications and use-cases examples, please refer to section 4 of this report).

Concretely, blockchain can be described as a sequence of blocks, which holds a complete list of transaction records like a conventional public ledger.[5] These transactions or contracts are enclosed in code and stored in transparent and shared databases where they are protected from deletion or change without the need for the involvement of lawyers, banks or brokers or any other trusted third party.

In the blockchain's context, the data structure of records is organized as chained-blocks in such a way that each new block includes information about the previous block using a cryptographic link in an append-only pattern. Along with clear rules for participation and data appending, this structure is designed to harden data records against tampering while providing transparent mechanisms to trace information in a peer-to-peer (P2P) network.[6]

By combining peer-to-peer networks, cryptographic algorithms, distributed data storage, and a decentralized consensus mechanism, blockchain technology provides a way for untrusted entities to agree on a specific state of things and to record this agreement in a resilient, accountable manner and able to inspect the scheme when needed. Figure 1 illustrates a simplified data structure and the main elements in a blockchain.

Figure 1: Simplified data structure



As an expected immutable chain of records, the first block in a Blockchain, i.e. the genesis block (also referred to as block 0), plays a key role as the entity providing the service might use it to validate all the following chain. From this point, every new valid block contains information related to its predecessor, binding them permanently.

The mechanism used to discernibly relate the blocks is called the hash functions, which consists of cryptographic functions that map a bit string of arbitrary length to a fixed-length bit string in such a way that:

(i) is computationally infeasible to find any data input that maps to any pre-specified output (i.e. digest);

(ii) is computationally infeasible to find any two distinct data inputs that map to the same output; and

(iii) the smallest change of input, even a single bit, will result in a completely different output.[8]

For blockchain's technology, in addition to the data being stored, every new block added to the chain (a process also referred to as anchoring) includes a header containing the result of a hash function for which input is the entire previous block. It means that to change any data in an anchored block, an update is required in all subsequent blocks, which would be computationally intensive. Even if a malicious participant is able to update all blocks in a chain, the technology's distributed and replicated nature will imply that the tampered copy will diverge from all the remaining copies. The scenario is one in which the consensus mechanism ensures that only the unchanged chain will prevail across the network of participants, thereby securing the database against tampering attempts. It means that, depending on the network size and the consensus mechanism adopted, data stored in a blockchain are virtually immutable.

2.2 Blockchain technology process

In the blockchain system, the distributed ledger is replicated in a certain number of similar databases, and each one of the copies is kept and maintained by one of the entities that are interested and involved in writing data. When one of these entities is changing data in one copy of the DLT, all the other copies are simultaneously and automatically updated. There is no need for a lawyer, a bank, the government or any third party to verify, validate the occurrence of a transaction such as a transfer of ownership.

There are five principles that explain how blockchain works:[9]

(1) The distributed database requires that each party on a blockchain has access to the entire database. All the parties in the blockchain can verify the records of the parties involved in the transaction without intermediaries. However, they do not control the data and the information recorded in the transaction.

(2) The peer-to-peer transactions mean that communications occur directly between peers without the intervention of a third party or through a central entity. Each of the nodes in the peer-to-peer network stores the data and forwards the information to all the other nodes.

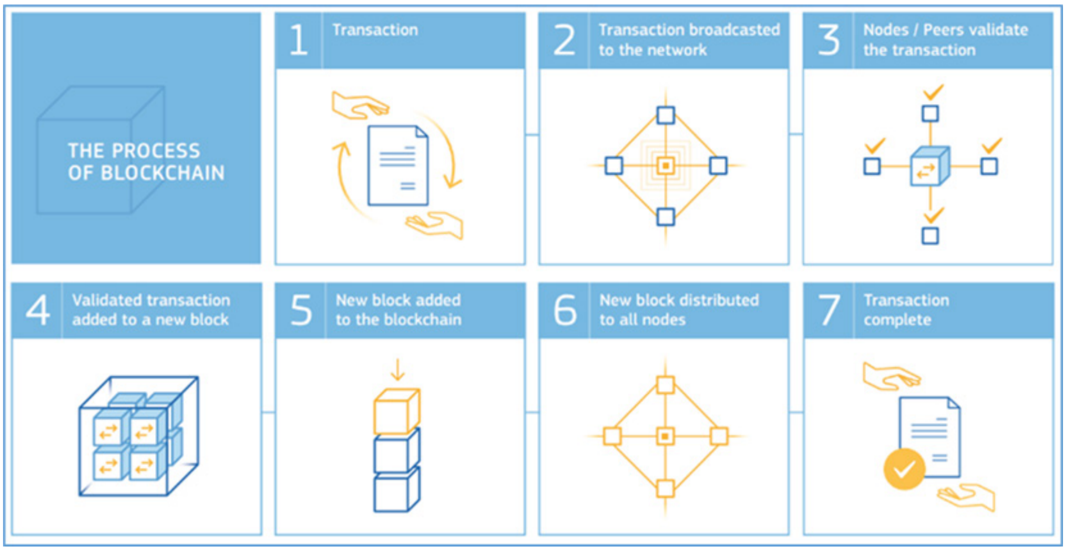
(3) The transparency with anonymity and pseudonymity provides information about the transactions and the associated value to all the participants with access to the network. However, it gives the actors the choice of remaining anonymous or revealing their identity and providing proof of it to the network. The transactions occur using the blockchains' addresses.

(4) The irreversibility of records entails the permanent character of the transaction recorded in the database, their chronological order and their availability.

(5) The computational logic explains that the digital nature of the ledger of the blockchain transaction can be programmed automatically through the set-up of algorithms and rules and trigger the transaction between nodes.

The process carried out by the blockchain to validate a transaction and to add it to the network is presented in Figure 2. The process starts with a node that initiates a transaction and signs it with its private key. Then a node representing the transaction request sent by one of the users will lead to the creation of a block on the platform. At this stage, this specific block is broadcasted to the peer nodes in the network based on any pre-defined criteria. Upon receipt of the information, the peer nodes validate the transaction. After the validation, the block is added to the ledger and linked to the chain (the previous block and when a new block arrives, it is cryptographically linked to this specific block). After validation, it is included in the block, and the transaction is verified and confirmed.

Figure 2: The process used to validate transactions in a blockchain[10]



In the case of a consensus blockchain (see Section 2.3), a consensus algorithm is running among the nodes in order to reach an agreement on whether it is valid or not. Various consensus algorithms exist, and each algorithm works differently from any other.

In the case of the smart contracts, which are specific types of legal self-executed contracts between two participants of the blockchain network, the process is defined by the creation of the contract between the two parties. Both parties might choose to remain anonymous. The rules for triggering events (i.e. deadlines) are defined at first. The smart contract is then stored on the ledger. The contract is then self-executed, and both parties can follow and track the progress of the execution. This type of transaction is used more in the supply chain management field.

2.3 Features and properties of blockchain technologies

The following subsections introduce essential aspects of blockchain. Combining the following elements increases the potential of the blockchain technology: (a) the consensus mechanism, (b) the timestamp of transactions, (c) multiple and distributed nodes, and (d) the smart contract.

To this end, this section will examine how the aforementioned elements contribute to:

(i) increasing the security of the system (with no central point of failure);

(ii) enabling the transactions between entities that do not trust each other without the dependency of a central authority;

(iii) enabling auditable and tamper-resistant records, with transparency and integrity.

(1) Consensus mechanism

The consensus mechanism (also called consensus protocol) defines strict rules for creating new blocks and adding new data to them without favoring one participant over another.[11] The consensus mechanisms validate transactions that will be bundled with others into a new block that will be added to the blockchain. Once a consensus mechanism is used, it is possible to have parties not trusting each other using the same distributed network and expecting the same set of rules to interact in the system.[12]

These rules ensure an agreement among participants on the validity of data insertion, the existence of a consistent set and guaranteed ordering of data to be stored in the distributed ledger. Usually, the consensus mechanism is adopted according to the type of blockchain being deployed, which defines who can join the network by setting up a copy of the database and its rights regarding reading and writing data to the ledger. It is possible to design a blockchain in which only some people or nodes can participate in the consensus mechanisms, and therefore only certain individuals/entities can validate the transactions.[13]

The Bitcoin was the first use-case of blockchain, and it is public and permissionless. This means that in this type of blockchain, everybody can participate in the consensus mechanism (See Table 2. *Examples of Blockchain types*) and there is no central control of transaction validation. In all the other types of blockchain, there is the possibility to control who can validate transactions.

The most known consensus mechanism is Proof of Work (PoW), and it depends on the processing power of the computers or nodes in the network to solve a complex mathematical problem. There are also other consensus mechanisms, such as Proof of Stake, Proof of Authority, etc.[14] Some consensus mechanisms referred to in this report are described in Table 1.

Table 1: Consensus algorithm[15]

Consensus Mechanism	Characteristics
The Proof of Work (PoW)	• The most common consensus mechanism requires complex mathematical resolution to generate a new block. • This incentivizes miners to connect multiple computer rigs to the system. • All of the nodes contain an identical record of transaction and history. Any altered version would be rejected by other users, making it so that tampering is highly unlikely. • As the number of participants increases, the complexity of the puzzle would increase in parallel along with the energy required to solve them. • The energy costs of PoW accounts for 90 percent of the total costs for operation.
Proof of Stake (PoS)	• Consensus algorithm that depends on the validator's economic stake in the network. • Creator of a new block is chosen in a deterministic way based on the amount of coin (i.e. the stake) they possess. • PoS is a much more energy-efficient option and has a lower risk of 51 per cent attack.[a] • Risk is the "nothing at stake" problem where block generators have nothing to lose by voting for multiple blockchain histories.[16]
Practical Byzantine Fault Tolerance (PBFT)	• Consensus algorithm designed to tolerate faulty or malicious nodes through reaching decisions by having the majority of nodes agree to the message (less than one-third of the total node). • Consensus can be reached quickly and efficiently. • Consensus decides on the validity of a block and the information on a proposed new block will pass through all the nodes. • Hashing power is not required in the process. • The system devised for a low-latency storage system (digital asset-based platforms that do not require a large amount of throughput yet demand many transactions. • Less energy-intensive than PoW since it does not involve any complicated puzzles.
Proof of Elapsed Time (PoET)	• Consensus algorithm requires participants' identification. • PoET is more common in a permissioned style blockchain than a public one due to efficiency reasons. • The wait time assigned to every individual on the network is completely random. Whoever finishes his or her fair share of waiting time will get to be on the ledger and create a new block.[17] • PoET prevents high resource utilization, energy consumption and operational efficiency. • One example of a blockchain network that uses PoET is the Hyperledger Sawtooth.
Proof of Authority (PoA)	• PoA does not require any mining activity.[18] • All transactions and blocks are checked with approved accounts for validation. • Transaction execution and block generation takes place automatically using just the computer power of the validator. • This provides a reduction in maintenance costs. • Key participants of the algorithm are validators leading to centralization.[19] • Relevant in private blockchain deployment and participants are trustworthy.[20]

Many other consensus algorithms may provide additional environmental and operational benefits that would improve blockchain usability in cities and can be considered a viable alternative to the PoW model.

[a] The 51 percent attack refers to the possibility of a miner controlling over 51 percent of the computational power of a network has been able to independently create fraudulent blocks for himself while invalidating the others. In order to carry out a 51 per cent attack in a PoS system, the attacker would need to already possess 51 percent of its currency, which would be extremely costly. Furthermore, it would not be financially rational for him to carry out the attack since the value of the currency is tied to the network (i.e. if the value of the network falls, the value of his holding would also fall).

(2) Time-stamped transactions

All the transactions in a blockchain are time stamped. Therefore, it is possible to track and verify the information, which means that the transactions related to payment, transfer of ownership, or contract are linked publicly to a specific time and date. It is not possible to modify the time stamp, and this feature is relevant for the identification of when a transaction was initiated, and by whom. This increases transparency and security. It also enables the validation of transactions and the update of records in a synchronized and decentralized way.[21]

It is not possible to delete or edit data in a blockchain, however, it is possible to add a new transaction that is time-stamped in the network. This maintains the history available for everybody in the system and allows for the information to be tracked.

(3) Multiple and distributed nodes

The blockchain is a database operating in a distributed network of multiple nodes or computers. There is no central point of failure in the system, which is why it is difficult to attack it. To target the majority of nodes simultaneously or break down the network is difficult. Potential collisions or attacks from a group of participants controlling the majority of computational resources might not be practical or feasible.

There are some concerns about centralization in private and permissioned blockchain such as Hyperledger because in this type of blockchain, it is possible to allow access and permissions just to a group of participants. Under such circumstances, it can be considered a centralized or semi-centralized model, at best.[22]

(4) Smart contracts

Smart contracts are programmes executed automatically and capable of carrying out the terms of the agreement between parties without the need for human intervention. Smart contracts can enforce contracts under instructions and enable two or more parties to perform transactions without the need for intermediaries.[23]

Smart contracts became popular with Ethereum, and although it has yet to reach a well-accepted level of maturity, it has been offered by other blockchain platforms, such as Hyperledger's umbrella project. Their implementation can be different in each platform. The assumption regarding smart contracts is that contractual control of transactions between parties can be confirmed through the blockchain instead of through a central arbitrator or authority. In such situations, it is possible to define the terms and implications of an agreement with automatic asset releases when fulfilling services in a certain manner or incurring penalties if not fulfilled.[24] Although it is possible from the technical perspective, and from the legal perspective, smart contracts do not necessarily have anything to do with a legal contract.[25]

These features and associated benefits (of consensus mechanisms, time-stamped transactions, multiple and distributed nodes) presented in this sub-section are the main advantages accrued through the use of blockchain technology (in comparison with traditional databases).

2.4 Type of blockchain

Blockchain can be classified into two categories public vs private and permissionless vs permissioned.

A private blockchain means that there is control over the user access to the network and the information. It is a network-based on "invitation-only" and is governed by a single entity, which makes it exclude one of the main defining features of blockchain – decentralization. On occasion, it might allow for different levels of permissions for the users. In this case, the access can be partially or fully restricted, and information can be encrypted for confidentiality. The participants in the networks must have permission to read, write or verify the data on the blockchain. It is considered less secure than a public blockchain. The public blockchain is considered as a transparent and open ledger all the nodes and the transactions are public. Given that public ledger is distributed and decentralized, the information is then encrypted and stored on multiple devices which increase the level of security of the public blockchain. The public blockchain is considered to be immutable, which means that once the data have been verified it cannot be altered.

The permissionless vs permissioned type of blockchain is associated with the permission level given to the participant to read, write and audit, as well as to commit to the network. The entities of the permissionless blockchain that write data are not known. In a permissioned blockchain, a limited set of known entities is authorized to write in the system.[26]

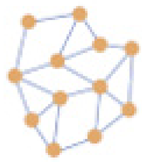
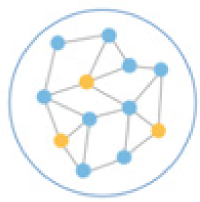
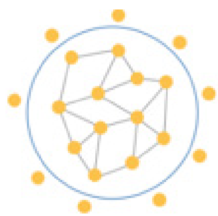
A combination of the different types of blockchain solutions is composed of blockchain architecture options. These options are presented in Figure 3.

Figure 3: Blockchain architecture options and differences[27]

Blockchain-architecture options		Architecure based on read, write, or commit permissions granted to the participants	
		Permissionless	**Permissioned**
Architecture based on ownership of the data infrastructure	**Public**	• Anyone can join, read, write, and commit • Hosted on public servers • Anonymous, highly resilient • Low scalability	• Anyone can join and read • Only authorized and known participants can write and commit • Medium scalability
	Private	• Only authorized participants can join, read, and write • Hosted on private servers • High scalability	• Only authorized participants can join and read • Only the network operator can write and commit • Very high scalability

Four blockchain architecture options are based on the type of ownership of the data infrastructure, public or private and the level of "read, write and commit" permission granted to the participants of the networks.[28] These options are often presented (with the technological development) as new hybrid blockchains that combine different aspects of the technology.[29] The following Table provides the explanation and a representation, as well as examples of blockchain for each architecture type.

Table 2: Examples of blockchain types

Blockchain Type	Description	Visualization	Examples
Public permissionless blockchains	This blockchain type is open to everyone worldwide with an Internet connection to participate in the blockchain consensus mechanism, to transact and observe the full transaction log		Bitcoin Litecoin Ethereum
Public permissioned blockchain	This blockchain allows everyone with an Internet connection to see the transaction log, however, only a restricted number of participants can contribute to the consensus mechanisms		Ripple Private version pf Ethereum
Private permissioned blockchain	These blockchain systems restrict the ability to transact and view the transaction log to only the participating nodes in the system. The architect (or owner) of the blockchain is able to determine who can contribute to the blockchain system and which nodes can participate in the consensus mechanisms		Rubix Hyperledger
Private Permissionless Blockchain	These blockchain systems are restricted in terms of who can transact and see the transaction log, although the consensus mechanism is open to anyone		Exonum (Partially)

The type of blockchain adopted differs from one sector to another sector. The public sector requires an in-depth analysis of what type of blockchain is the most adequate because as presented earlier, all the blockchain types have their benefits and trade-offs for every type. The decision on the type of blockchain technology adopted has an effect on the control, security, data ownership, and privacy and access. The government must take into consideration serious privacy issues that the type of blockchain involves in terms of sharing and storing sensitive data (personal, health, etc.).

2.5 Blockchain potentials, challenges and implications

Blockchain is a technology that is impacting the world of finance through the cryptocurrencies. It is now transforming other fundamental aspects of society, particularly with reference to how governance is carried out at the regional, national and local levels. The governments and public service sectors are increasingly interested in the use of blockchain technology. The technology is presented with great potential and offers solutions and relevant opportunities at the national level, local and city levels. Table 3, below, summarizes some of the promised opportunities and benefits of blockchain technology.

Table 3: Opportunities of blockchain[30]

Categories	Opportunities and Benefits of Blockchain technology
Strategic	Transparency, avoiding fraud and manipulation, reducing corruption.
Organizational	Increased trust, transparency and accountability, predictive capability, increased control.
Economical	Clear ownerships, reduced costs.
Informational	Increased resilience to attack, data integrity and high quality, reducing human errors, information access, privacy, reliability.
Technological	Resilience, security, persistency and immutability (irreversibility).

Most of the studies highlight that the adoption of blockchain by government and public services is still minimal. It also underscores the lack of empirical evidence of the adoption and overall success rates. A limited number of studies have measured the implications of blockchain technology. The uncertainty and complexity of the technology are affecting its adoption level. Blockchain technology is not the first technology to which organizations and institutions are struggling to adapt. The main challenges, as presented in Table 4, are technological, organizational and institutional.

Table 4: Challenges and barriers of blockchain technology[31]

Categories	Challenges and barriers of blockchain technology
Technological	Immature technology, security, Scalability, flexibility, data privacy, cost and performance, energy consumption, interoperability, complexity, limited technical skills
Organizational	Feasibility, acceptability governance model, organizational readiness, leadership readiness, business model alignment
Institutional	Legal framework, regulatory uncertainty, ethical parameters, inter-organizational relationship, ecosystem readiness

Blockchain technology still faces several challenges. The most cited and discussed challenge is the high level of energy consumption. The proof-of-work consensus algorithm has proven to be a critical component in establishing trust in the Bitcoin network. However, managing data via blockchain can be an energy-intensive process. Data contained in a PoW blockchain exist in many copies. The computational resources required to calculate, transmit, store and update information typically grow in proportion to its size. The more participants there are in a blockchain, the more energy it consumes. As a result, this mining process encourages a large number of computer rigs to be connected to the network at all times, in order to maximize the chance of obtaining the reward from successful mining. In 2019, the energy consumption of cryptocurrency was estimated to be 73.17 TWh, which is comparable to the power consumption of Austria.[32] Another energy-related issue is the energy source that is being used to power blockchain activities. It is a well-known fact that coal-fired power generation is the single largest source of carbon emissions. If blockchain is to be scaled up for city and community applications, it must be made more efficient and less energy-intensive. One way to do it is to switch to using renewable energy to power the blockchain.

While energy consumption is one of the significant barriers to large deployments, a wide range of technical and legal barriers hinder a broader application and scale-up. Blockchain interfaces are too complex and inconsistent for mainstream adoption. The user interface is designed differently depending on the capability and purpose of the blockchain. Without a standardized interface, citizens would have to learn and relearn how to operate each blockchain application individually. This poses a significant challenge for cities and communities considering the development and delivery of blockchain-based social services.

Blockchain performance is also relatively weak and costly. The data of every block must be replicated in every node for every transaction, which is a time-consuming and energy-intensive process (particularly in the case of PoW). Therefore, blockchain does not scale well with applications that require a large volume of metadata to operate, which would include the majority of city services.

There is a lack of interoperability and regulation in blockchain applications. Many blockchain networks exist in many different formats. As more participants are looking into leveraging blockchain for different purposes, a diverse set of blockchain projects has emerged. Each of these projects uses different terminologies, coding languages, consensus algorithms and privacy measures. There is currently no standard that would enable them to interact with one another, and with other existing applications or digital platforms.

In order to fully harness the potential of blockchain for cities and communities, a new study that focuses on blockchain's operational and energy efficiency is required. International groups such as the Focus Group on Artificial Intelligence and other Emerging Technologies (FG-AI4EE) have already taken the first step to identifying the environmental requirements of blockchain. Established in May 2020, ITU-T Study Group 20 on IoT and Smart Cities and Communities (SG20), focuses on the development of standards that leverage IoT to address urban challenges in the 20th century. [33] As a part of the work carried out by SG20, it has approved several standards on end-to-end architectures for IoT, the interoperability of IoT applications and management of datasets across different verticals in the IoT ecosystem. More recently, it has also initiated standardization work on blockchain within the IoT domain. In this context, SG20 has developed one standard on "Framework of blockchain of things as decentralized service platform" and is working on six additional standards (blockchain-based IoT communication architecture, blockchain framework for IoT, blockchain-based data management, blockchain-based data exchange, blockchain for data processing and management, and reference architecture of blockchain-based unified KPI data management).

3. Blockchain for smart and sustainable cities and communities

3.1 Current situation and context

Globally, the concerns of cities have become increasingly prominent due to several convergent trends:[34]

- Cities are the epicentre of human habitation and also form the building blocks of the economy, while serving as the basis for global innovation. With their core infrastructure, cities facilitate exchange of information, capacity building and foster the provision of knowledge-intensive business services. This makes it essential to have credible frameworks to be able to further guide socio-economic developments within the urban realm.
- Cities are attracting an ever-increasing proportion of the global population. In 2014, fifty-four percent of the world's population was located in urban areas, a number that is growing continuously and is expected to reach sixty-six per cent by 2050.[35]
- Cities are playing a more prominent role in the economy and welfare of nations, with most economic activity being in cities. At the same time, cities are facing administrative, organizational, logistical, social and environmental challenges.
- New political and social trends are changing the relationship between cities and residents; including better access to information, greater transparency, less tolerance of corruption, improved administrative efficiency, new models for citizen participation and greater awareness of the value of electronic information and the need to protect it.
- The density of city populations is straining the environment and raising concerns relating to lowering energy consumption, exploring alternative energy sources, providing cleaner air, reducing noise pollution, managing waste, and preserving and protecting natural resources, including green spaces.
- Rapid and disruptive technology development in areas such as communication, informatics, data mining and robotics are precipitating widespread, and unpredictable social changes.[36] In line with this, society is developing towards a hyper-connected information society with consequences that, while mostly positive, may also cause harm, and could be difficult to anticipate.[37]

The increasing population of cities creates many challenges related to the quality of life of their inhabitants: the need for economic growth, the increased strain on infrastructure and public services, and the environmental impact of dense cities. These challenges are central concerns among the proliferating smart initiatives based on ICTs for more efficient management of the resources of the city. The pervasiveness and ubiquity of ICTs in daily life, as well as the rapidly falling cost of technology, data storage and connectivity, have opened up substantial, underused intelligent approaches to the city administration, resulting in the emerging concept of the "smart city".

3.2 Smart Sustainable cities and communities

There is increasing interest in "smartness" around the world, and large investments are being made to make cities and communities smart. China has been developing more than 200 smart cities.[38] Launched in 2015, India's "Smart Cities Mission" includes more than 100 cities.[39] More recently, the United States has developed the "Smart Cities Initiative",[40] while Spain promotes smart city activities through its "National Smart Cities Plan".[41]

Smart city projects were initially based mainly on the capacity of technological platforms, communications networks and specific hardware in monitoring and controlling local public services, such as vehicle traffic, water supply or energy. Analysis of the data collected by such tools helps optimize the management of urban territories. Over time, however, the focus of these projects has moved from a purely technological perspective towards the effective improvement of the services provided to residents, including projects that are initiated by residents themselves.

Despite the prominence of cities, there is also a growing recognition of the diversity of communities that equally need to address their challenges through the use of ICTs. As thinking has shifted towards more systemic understanding, the inter-dependence between urban and rural areas has been acknowledged and hence the idea of being smart is increasingly being applied to communities of various sizes and configurations that go beyond the definition of city or municipality (such as villages, neighbourhoods, parishes or even islands). This idea has also been expanded to smart territories or regions to include joint projects that cover areas that maintain economic, environmental and social relationships with each other.

3.2.1 What is a smart sustainable city or community?

The idea of smart cities and communities emerged in the late 1990s and early 2000s with initiatives in the United States (San Diego as a City of the Future), Canada (a national Smart Communities initiative), the United Kingdom (Southampton as the self-recognized "first smart city"), Singapore (the Intelligent Island), India (Bangalore as India's Silicon Valley) and Australia (Brisbane's sustainable urbanism).[42] Since then, the terms "smart city", "intelligent city", "digital city", "sustainable city" and "resilient city" have all been explored, defined and debated at length. The terms have also vied for prominence and authority in the past two decades, with the composite concept of "Smart Sustainable City" now being widely accepted.

While the terms remain ill-defined, and thus refreshingly open to local interpretation, there have been attempts to distill from these debates the essential elements, or essence, of a city that is trying to work in better ways and use technology to do so.

One of the attempts to understand the essence of the smart, sustainable city was made by the Focus Group on Smart Sustainable Cities (FG-SSC) set up by ITU. This group examined the definitions that were in use at the time, to identify the common elements. They put forward the following definition (in March 2014):

A smart sustainable city (SSC) is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects.

This definition was further streamlined together with other United Nations agencies, under the purview of the United for Smart Sustainable Cities initiative (U4SSC) and the ITU-T Study Group 20 on IoT and Smart Cities and Communities:[43]

A smart sustainable city (SSC) is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental, as well as cultural aspects.

This definition encompasses the major attributes of a smart city: innovation, the use of ICTs, the goals of improved quality of life, efficient operations, and competitiveness, as well as the long-term consideration for sustainability. These elements are generally thought to be common to smart initiatives.

While much of the smart city literature appears to focus exclusively on cities, an understanding that communities of various sizes can be smart has a similarly long history. In the Smart Communities Guidebook, developed by the State University of San Diego (1997), a smart community is described as:

A geographical area ranging in size from neighborhood neighbourhood to a multi-county region whose residents, organizations, and governing institutions are using information technology to transform their region in significant ways. Co-operation among government, industry, educators, and the citizenry, instead of individual groups acting in isolation, is preferred. The technological enhancements undertaken as part of this effort should result in fundamental, rather than incremental changes.

Thus, smart initiatives can be undertaken by any group of people who live in a defined geographical area and who share resources, infrastructures and services, using information and communication technologies to achieve greater efficiency in their management, with the aim of achieving a higher quality of life and the sustainability of its environment.

The definition above, in addition to expanding the scope to smart communities, reinforces the fact that the changes that are implemented must be fundamental, in the sense of pursuing not only an improvement in the indicators, but also in the way of urban development. The idea of innovation is repeated in this definition by Smart Community International Network (2003):

> *A Smart Community is a community with a vision of the future that involves the application of information and communication technologies in a new and innovative way to empower its residents, institutions and regions as a whole. As such, they make the most of the opportunities that new applications afford and broadband-based services can deliver – such as better health care delivery, better education and training, and new business opportunities.*

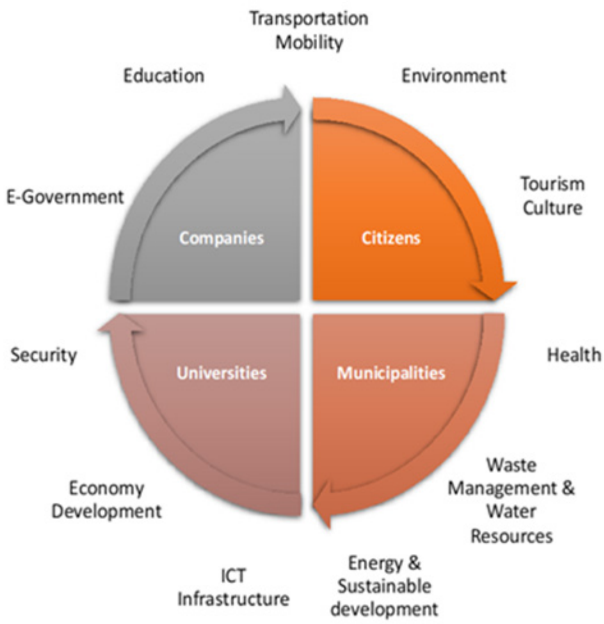
3.2.2 What makes a city or community "smart"?

There is a wide debate about the characteristics of a smart city and how to determine which cities are smart. Some of the characteristics of a smart city which have been identified (by FG-SSC) include:

- The effective use of ICT infrastructure and systems, and of technology and data.
- A good and improving quality of life for residents, along with the provision of efficient public services.
- Economic growth, higher living standards and greater employment opportunities.
- Improvements in medical care, welfare, physical safety and education.
- An environmentally responsible and sustainable approach with a long-term perspective.
- Streamlined physical infrastructure-based services such as transportation (mobility), water, utilities (energy), telecommunications, and manufacturing sectors.
- Prevention and handling functionality for natural and human-made disasters, including the impacts of climate change.
- Effective and well-balanced regulatory, compliance and governance mechanisms with appropriate and equitable policies and standardized processes.

Research and studies tend to agree that the elements of a smart city can be observed in three broad areas: (1) actions and initiatives with economic outcomes, (2) those focused on the occupants of a city or community and (3) those that focus on the environment. Other models for smart and sustainable cities have emphasized that there are several domains in which the city needs to perform adequately. A study has identified ten main categories for smart city initiatives (see Figure 4, below) encompassing 85 concrete actions or solutions that have been deployed or in the process of deployment.

Figure 4: Categories of smart cities initiatives[44]



The specific choice of domains differs between studies. However, the most commonly accepted set of six dimensions is (1) smart economy, (2) smart mobility, (3) smart environment, (4) smart people, (5) smart living and (6) smart governance. Each of these domains offers tools to achieve integrated and open governance, promote cooperation and co-decision making, while integrating active participation of citizens.

(1) Smart economy

City economies are vital to their continued existence and success. Smart solutions offer ways to improve the economy through greater interconnectedness to suppliers and markets, through the exploitation of aggregate data for the elaboration of detailed consumption profiles, and through employment opportunities created by the implementation and maintenance of telecommunications infrastructures and technology platforms that serve as support for smart services. The application of new technologies to production processes can increase efficiency and create new businesses.

Smart city technologies create opportunities for entrepreneurs to service the demand for technologies and create new information-based products. There are opportunities to innovate business processes and existing products, and smart methods allow the revitalization of economic activities that are currently in decline such as smart farming, which may then slow the rural-to-urban migration.

(2) Smart mobility

Technology developments that support smart mobility include improvements in managing city traffic flows and emergency response systems, improved information about transport options and better matching of public transport supply to the demand by residents. These technologies can help to improve current mobility solutions in cities by improving what we know about them and by intervening to increase efficiencies in these systems.

For example, it is possible to have artificial intelligence algorithms analyzing traffic flows and adjust traffic lights to make traffic flow better. It is also possible to use cellphone data to understand where bus passengers are waiting and to dynamically increase or decrease the number of buses on a route.

New technologies, like driverless cars, platforms for car sharing, public transport vehicles with larger capacity and lower environmental impact and the use of drones or small delivery robots in the city streets all point to the possibility of reconfiguring the city in the future. As individuals find that they depend far less on private cars, cities should experience reduced traffic and demand for parking and be able to increase the space allocated for pedestrians in the city. Cities of the future will change to reflect the adoption of these new smart technologies.

(3) Smart environment

Smart technologies promise long-term improvements on how natural resources are used. Cities are able to change their power supply to cleaner, renewable sources. Changes in transportation services and more efficient heating and insulation can also significantly reduce the demand for power, as can responsive lighting systems. Feedback on usage enables better planning and management of power supplies. Monitoring levels of pollution has helped cities and communities to develop strategies for cleaner air, quality water provision and the improved use of natural spaces.

Smart systems can be used to better understand the climate-related risks that cities and communities face and to put in place mechanisms for dealing with them. The holistic and systemic approaches used in smart city management sensitize managers to the inter-connectedness of city systems and the need for multiple systems to function in harmony. In particular, ubiquitous sensors that detect changes in temperature or in the environment (e.g. pollution-levels or weather changes) can detect hyperlocal toxicity levels and also warn about natural catastrophes such as fires, floods or earthquakes. Smart tools and drones can also be used to keep residents informed about what to do in an emergency and can be used to manage emergency situations more effectively.

(4) Smart people

There is an understanding that a smart city is more likely to thrive when it is populated with smart people. Smart people are understood to have certain characteristics such as being well educated and life-long learners, having a cosmopolitan and open-minded approach to life, being flexible and creative and being engaged in city life. Smart people are more likely to be highly-skilled, entrepreneurial and to contribute their skills and energy to the city. As part of the regulatory role, several cities reposition their city-wide ecosystems, allowing greater private sector participation. By transitioning to smart cities, cities worldwide are providing a conducive environment through supportive policies to encourage entrepreneurs to innovate and develop ideas relating to advanced smart city solutions to cater to the needs of the citizens.

Smart city initiatives thus include ways to encourage smarter residents by offering them opportunities for self-development and growth through technologies designed to teach skills and expose them to new and different ideas and engagement channels. Such initiatives have the potential to transform the workforce in a city.

Smart cities also seek to attract smart people, who are often highly mobile and willing to migrate.

(5) Smart living

Smart people are drawn to places that offer high standards of living by providing good housing, health and education services and personal safety. Smart cities also provide opportunities for citizens to benefit from tourism, and cultural and leisure activities.

The implementation of measures to control the environment and the quality of air and water, the elaboration of sound maps, the traceability of food, the intelligent management of waste and street cleaning, the use of monitoring systems of the human body, together with more efficiently managed health services can all contribute to the overall improvement in the health of people living in cities. At the same time, vehicle traffic control systems, mobility as a service, better information on public transportation and information for improved traffic flow (incorporating detection of vacant parking spaces in urban environments), can reduce traffic accidents and the stress associated with the time spent in daily commuting. Improving these aspects of city life will also mean an increase in free time and recreation, leading to a healthier and happier population.

(6) Smart governance

Smart city platforms provide local decision-makers with more accurate information that will allow more effective management of the natural environment, historical heritage, public resources, and city services. Real-time information about city services and infrastructure allows for the immediate detection of faults and incidents in the public space, facilitating rapid responses. The provision of electronic administration services can be expanded to remote settlements, allowing all residents to enjoy similar levels of service from local administrations.

Smart technologies can be used to improve the flow of information for city or community management, and between residents, businesses, consultants and other stakeholders. The effective dissemination of information can make all stakeholders more aware of the issues, concerns and goals of others in the city. This will make it easier to negotiate priorities for the city or community and ensure that there is support for smart city goals and projects. A wider understanding of the SDGs and how each city or community is working towards them is essential so that stakeholders can take a long-term view and execute projects with more distant payoffs.

3.2.3 Sustainable cities and communities

The sustainable development of the cities and communities is reflected in the SDG 11 *to make cities and human settlements inclusive, safe, resilient and sustainable*. The density and economic concentration of cities mean that they need to work effectively for all the SDGs to be met since they are the centre of concentrated human activity and habitation.

The sustainability of cities and communities depends on the efficient management of resources to allow for their equitable use by all citizens.

The characteristics of the urban environment often do not provide enough space for the generation of renewable energy, supply of potable water, agricultural exploitation for the production of food, extraction of raw materials for industry, and adequate green space for a healthy environment.

Such resources are normally sourced and generated in rural areas, which maintain strong ties with urban centres, guaranteeing a constant supply that allows for their survival. Cities, in order to be sustainable, need to cultivate deeper connections with rural settlements. This means that sustainable cities depend on having concrete links with sustainable rural communities. Therefore, the application of smart solutions in rural areas to solve inherent social, environmental and economic challenges is of equal importance. This interdependence has been recognized in Goal 11A of SDG11, which aims to "support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning".

Some researchers have questioned whether the goals of being smart and sustainable are compatible, pointing out that many smart initiatives make additional infrastructure and energy demands that might work in opposition to the core sustainability goals. These criticisms are worth bearing in mind while assessing the value of smart interventions for cities and communities. Thorough strategic thinking that takes into consideration a vision of sustainability will allow sustainable benefits to be derived from the implementation of technologies which, in turn, are expected to solve urban problems and improve the quality of life.

3.3 Smart city and community challenges

Several challenges have been identified for those cities and communities wanting to become smarter. Some of these challenges are at a high-level, and have to do with how people perceive cities and their place in them. Others are more practical concerns linked to how to make smart initiatives work.

High-level challenges

The first challenge of smart cities is to develop a shared understanding of what "smart" means for each city. There will be competing ideas of what matters in the city, which challenges to address first and which goals to pursue. As long as different stakeholders are aiming for different goals, they will work against each other and waste resources in the process. For this reason, mechanisms to build understanding and consensus are an integral part of becoming smart. It is important to note that this overall process given these impediments can be difficult and time consuming to manage in an efficient manner.

Becoming a smart city or community requires a long-term perspective since complex or costly changes, adjustments and investments may be necessary to put in place the infrastructure and regulatory frameworks needed to underpin smart systems. When city employees, businesses and residents have to make changes to their routines, it can be difficult if they are focused on the short term. Politicians too, are inclined to look for results that will fall within their terms of office, which can make it even more difficult to gain support for initiatives with longer-term benefits. Additionally, the automation of certain processes within the urban ecosystem also brings about the fear of phasing out certain occupations.

Developing countries embarking on their smart city journey may also face another daunting challenge of managing corruption. In light of the aforementioned challenges, the actual implementation of smart initiatives may take years, or even decades. As the people involved could change, continuity needs to be managed strategically, in order to take projects to a successful conclusion.

The installation and operation of systems or elements of new technologies in public spaces and public buildings can sometimes be a nuisance and an obstacle to people who are not familiar with the project's objectives. This can lead to a rejection of the smart initiative that, if widespread, could have been beneficial for the overall smart city transformation. For this reason, cities and communities that are open to change are more successful in becoming smart. Cultivating this attitude requires good communication and trust between stakeholders.

One of the challenges cities and communities are facing is that of competing priorities that need to be addressed. On the one hand, it is difficult for cities to decide which matters to attend to first. In such situations, cities need to develop definitive criteria to assess which initiatives will have the most impact on the stakeholders with the greatest need. On the other hand, even if priorities are clear, there will always be projects that cannot be implemented with available resources. In this case, being able to partner with other organizations and facilitating open innovation in the city will be necessary to foster the contributions from others for developing the city or community.

Implementation challenges

The implementation of smart city initiatives leads to several interrelated challenges, due to their reliance on data and communication networks.

There exists the challenge of accessing, compiling, normalizing, validating, analyzing, and sharing and trading of data. Different government agencies have traditionally taken responsibility for data in their domains, resulting in siloed attitudes and systems that operate in isolation. Since many smart initiatives depend on sharing and processing large amounts of validated, often real-time data, there are challenges pertaining to who owns the data, which data can be shared and for what purposes. Additionally, there are technicalities for sharing data across diverse platforms. In certain situations, some data could also be owned by private entities that have their interests and privacy to protect.

One of the challenges for sharing data is that agencies struggle to trust the accuracy and quality of data originating from other sources, and they are reluctant to allow changes to data where such changes are outside of their control. Given the importance of records relating to citizenship, health or property ownership, for example, such concerns are valid. Lines of responsibility for data need to be clear and changes to data need to be traceable and auditable.

Trust is also a desirable aspect for smart city initiatives. This includes trust between different government agencies, between government and residents, and between government and suppliers. However, these parties often have different agendas, unequal power bases and conflicting goals. Establishing trust in such situations can be difficult and can impede projects. One obstacle to establishing trust is a lack of transparency; however, transparency can be difficult to guarantee, particularly in situations where one party has control of data and another does not.

The reliance on smart solutions in communications technologies gives rise to concerns for security in the field of smart initiatives. Some of the cyberattacks with the greatest impact have emerged from IoT networks. In addition, smart solutions often rely on having personal information on city platforms that can be used to create profiles of citizens and this raises the question of privacy and protection of personal data. The challenge for cities and communities is to ensure that the legal frameworks and appropriate technical measures are in place to reduce these risks and ensure sufficient public confidence to support these initiatives. There is a complex balance to be struck between security and accessibility, and the means to achieve this is still evolving.

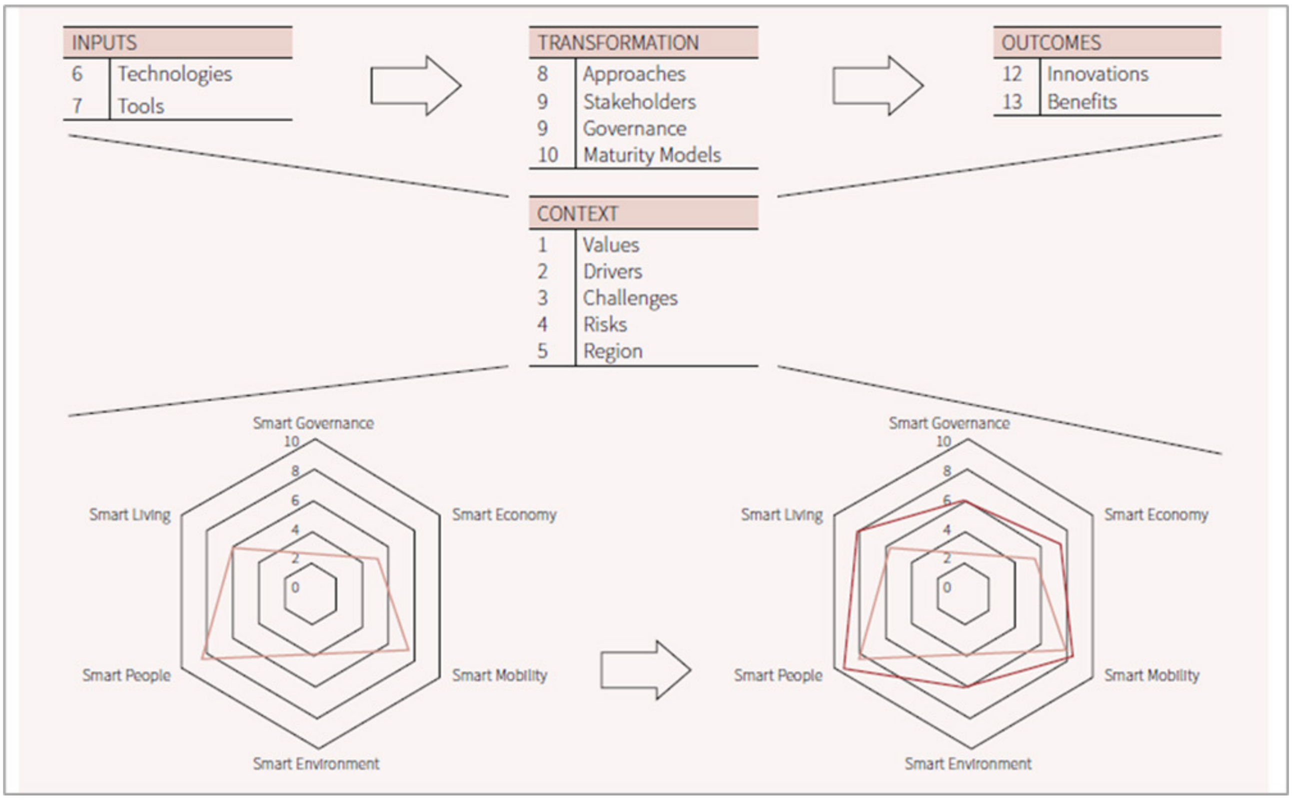
Smart initiatives may necessitate new policies and regulations for their implementation and operation. This might be to take account of new technologies, such as driverless cars; or to facilitate new ways of working together, such as purchasing regulations to facilitate crowdsourced solutions. In many cases, regulations do not facilitate the implementation of private infrastructures in the public space, or the use of new technologies for communication between residents and local decision-makers. This creates a serious problem of legal insecurity for those interested in developing smart initiatives. New regulations need to be developed and mechanisms need to be implemented to enforce their use.

There is a challenge in financing the implementation and operation of smart solutions. Many smart initiatives involve new technologies and standards that are not widely tested, with a consequently greater uncertainty regarding their success. This is an obstacle to motivating investment in them. Currently, many smart city initiatives are funded by government sources either at the local or national levels, which is often justified by the prospect of increasing revenues or decreasing costs associated with public services. However, this exerts great stress on the public budget. Other smart projects are financed by public-private partnerships, the private sector, donors or individuals. For cities to access a wider range of funds, business models need to be explored that encourage the private sector and other sources of funds to be part of these initiatives, and this calls for appropriate contractual arrangements and management of contracts.

One way to understand smart cities is the framework developed by UNU-EGOV that incorporates these six domains and also maps the process of becoming smarter in terms of the context, inputs, transformations and outcomes as shown in Figure 5. The effective design, operation and management of the smart city are not just about technologies and also involve strategies and processes. Problems are identified in any one of the six domains and are prioritized in terms of a city or community's context. Smart technologies and tools provide the means to address these; however, there needs to be a transformation process during their application, in order to achieve the desired outcomes.

"Smartness" depends, therefore, on a vision of an excellent city or community performing well in a number of areas, and the effective harnessing of the city's endowments through the activities of competent and aware stakeholders including officials, private companies, social entrepreneurs and individual residents.

Figure 5: Smart sustainable city and community framework (UNU-EGOV)



It is important to note that smartness is not an on-or-off state, where a city is either smart or not. Rather, smartness is a continuum along which cities and communities will find themselves positioned due to their history, geography, resources and initiatives. The task of cities is not to reach some ideal state in which they will earn the title "smart", but rather to improve and move along the continuum to a state of increasing "smartness" based on where they started their journey from. Taking this approach means that smart initiatives can be applied in large and small communities, depending on their stage of transformation to a smart ecosystem.

Cities and communities are, and will most likely continue to be, central drivers of economic growth and sustainable development. However, to sustain and enhance this role, cities face many challenges in trying to provide good-quality living experiences, economic stability and long-term sustainability. In response to these needs and challenges, a promising solution is to incorporate technology to a greater degree in the management and operation of cities and communities. The deployment of integrated information and communication technologies for the management of cities and communities, and in aspects of life and trade, in ways that support the human experience and protect the natural resources of the planet for future generations, is the ultimate vision of "smartness" and sustainability.

4. Blockchain for cities: use-cases

4.1 Blockchain for cities

As stated previously, a smart city fosters interaction among citizens, the public sector, and other stakeholders such as the communities using digital technologies to improve quality of life, efficiency and security. Blockchain, through its continuous distributed ledger, allows and multiplies the possibilities of interaction models which could not be designed by centralized models.[45]

The concept of "smart cities" is presented as one of the key areas in which blockchain-based applications are expected to drive radical and disruptive innovations. Blockchain arises in an era in which the management and services of cities are being digitalized and are developing their "smart cities" initiatives. Public administrations at all levels worldwide are facing a growing demand to fight corruption; to improve the efficiency, transparency and security of their systems; and to develop a more collaborative, interactive and democratic platform for the provision of services. Blockchain holds the potential for the improvement of many of these aspects through transparent, neutral, non-hierarchical, accessible, non-manipulable and secure information and value platform.[46]

Blockchain is considered especially suitable for environments in which there are multiple stakeholders and low levels of trust between the actors, which is one of the main features of the complexities and the governance of current urban cities.[47] Some studies proposed models of classification of blockchain technology applications and use-cases.[48] These related efforts of organizing the blockchain technology applications are particularly useful for analyzing the data. However, some of these categories could be difficult to use and apply, especially in the smart city context. For example, a smart contract category could be applied to different domains and be combined with other applications in the same use-case. It is also challenging to classify some blockchain-based smart city initiatives between dynamic and static hyperledger exclusively, when it is often used in combination with other technologies that could impact the properties.

For this report, it was decided to explore the potential of blockchain-based applications and organize them in the context of the smart city domain. Given that blockchain for cities can be implemented by governments as well as by private entities or other stakeholders, it is relevant for different verticals of smart cities. In tables 5 and 6, examples of potential blockchain applications that can be adapted for smart cities are presented and organized by verticals. It is possible to find examples associated with the governance, administration and government of a smart city. The purpose of these applications includes the optimization of the sustainability and reduction of externalities.[49]

Table 5: B4C applications in smart Governance, smart people and smart community[50]

Blockchain potential applications for Smart Governance, smart people and smart community	
Blockchain for democracy and decision making	"Smart Decision making" This includes the improvement of the participation and involvement of the citizens in political processes at all levels. Blockchain can offer new disruptive models for decision making with functionalities such as: the possibility for citizens to engage and participate more directly, real-time participation in voting processes; new ways for politicians and experts to build credibility and authority; and the possibility to delegate votes to authorities within specific areas (under certain circumstances).
Blockchain identity	Blockchain can provide solutions for decentralized identities without the use of a third-party authority and even without revealing more information than necessary for the specific interaction required for identification. Digital identity is a use-case for blockchain in government services, as well as a key for the integration and functionality for many other blockchain services.[51] QualiSig is a newly initiated project which utilizes Austria's digital identity system to counter problems related to fraud prevention, fake news and health data during the COVID-19 pandemic. Leveraging on blockchain, QualSig will be capable of verifying identities for the arrangement of tests, appointments and communication of results. For door-to-door testing, blockchain can help to identify testing personnel. To tackle concerns related to data security and privacy, users will be able to control their data and enable them to share it as they see fit.
Blockchain voting	This involves the design of e-voting systems that are secure, transparent and trustworthy, and still capable of preserving confidentiality. With reference to current use-cases, the city of Zug has used their blockchain IDs to conduct their first blockchain-enabled e-vote. West Virginia (United States) and Moscow (Russia) have also proposed voting based on a blockchain platform.
Blockchain for public accounting, contracts and taxes	In accounting, all the incomes and payments can be scanned and registered on blockchain for full accessibility to show for what, by whom, and when every single cent has been spent. Smart contracts can support taxation in real-time, and also show who has paid their taxes and who has not. The full information about any public contract, with the conditions, deliverables, and payments, can also be shown and followed up in real-time. Estonia has a considerable portion of its public administration based on blockchain. Many other countries and cities are starting to implement blockchain. For example, the public administration of Dubai will be digitalized, and paper free by 2021.
Blockchain for law enforcement and legal systems	The registration of data for police records and legal cases on blockchain would add trust to the legal systems due to transparency and immutability. Currently, the legal systems in many countries suffer from a lack of transparency, slow access, and vulnerability to manipulation. Many blockchain projects for law enforcement and judicial systems have been proposed globally, such as the tracking of the use of police firearms and the registration of police video surveillance to make sure data are registered and not manipulated or tampered with.
Blockchain for title and asset registration	To avoid the loss or manipulation of public registers, blockchain has been proposed for the registration of land and other properties. Moreover, with the use of Smart Contracts, the changes in ownership could also be done in real time. The Swedish public land registry has a project using blockchain for land registration, and many other countries are doing the same. Other areas where blockchain has been applied for registration are for example car registers in Denmark or the filing of companies and firearms.
Blockchain for certification	Blockchain systems can give real-time access to certifications regarding individuals and organizations. At the same time blockchain can let the individual, or organization, be the owner of their data; however, with the guarantee that the information is real and up to date. The potential here is vast, and the importance of these solutions has been widely recognized. An example is Malta, which will commence the issuance of blockchain certificates for professional and informal education.

Table 6: B4C applications in smart living, smart environment and smart mobility[52]

Blockchain potential applications for smart living, smart environment and smart mobility	
Healthcare services	The Blockchain offers new ways to manage public health services built upon a Token Economy (i.e. reward good behaviour with "tokens"), which would provide: a more efficient and transparent system; a tool to incentivize desired behaviours; and the possibility to apply data analytics and artificial intelligence easily to improve services and healthcare strategies.
Education	Blockchain could help in several ways to create a better educational system with more flexibility, transparency, and adaptation to individual needs. The whole educational journey could be developed based upon individual needs and capacities, with the registration of study plans, results, grades and certificates on blockchain. The data would at the same time be owned and controlled by the students themselves. A Token Economy could additionally distribute tokens to the citizens to access lifelong education, both to incentivize specific learning, as well as to fulfill anybody's desire to learn.
Social care	Blockchain can be useful in the evaluation system for benefit distribution, by using smart contracts, which would provide fair, fast, efficient and transparent handling. A Token Economy can also be used for the distribution of tokens for the payment of different services and products. These can, on the one hand, be conditional on incentivizing or controlling a specific behaviour and, on the other hand, they can benefit the receiver as they would be able to pay services and products with tokens, without the seller or provider knowing that the social welfare system is funding it. Several countries, among them Australia, are currently looking into using blockchain for welfare payments.
Mobility and transportation	Mobility and transportation are critical services for the efficiency and productivity of cities, as well as for the quality of life of the citizens. Blockchain offers interesting solutions to improve transport and mobility. Blockchain would, for example, provide payment platforms, for services such as tolls, parking, emissions or transportation, for vehicles and users. Also, it could form a part of the collection, sharing, and analysis of relevant data to improve mobility. Blockchain can also be utilized to facilitate the provision of shared services. In this context, a peer-to-peer, short- term, car-sharing application based on blockchain technology and smart contracts can support the car-sharing market as it leads away from centralized database server that could be prone to attacks.
Environment	Sustainability and habitability are two of the main targets cities are aiming to achieve in line with the global sustainable development goals. Actions have to be taken on a global and local scale, and blockchain can offer a high added-value. Blockchain is, for example, a perfect platform for supporting the circular economy due to its ability to track material within their lifecycle or specific supply chains, where it is currently applied in many cases. It could also be utilized in applications for the management of air pollution, waste recycling and water quality registration.

Table 7: B4C applications in Smart economy[53]

Blockchain potential applications in Smart Economy	
Energy	Blockchain is being applied in traditional business models and in new disruptive models that are emerging within the energy sector. Blockchain can be utilized for optimization of grid management and distributed energy networks. These new models have the potential to cut costs, while increasing energy efficiency, supporting renewable energy integration, improving resilience and enabling genuine local markets for energy trading, with optimal supply-demand balancing. Blockchain is used to enable peer-to-peer (p2p) transactions between citizens and tracking of energy units, particularly those generated by renewables.
Telecommunication	The telecom industry is moving towards hyper-connectivity, where the number of objects connected to the Internet with IoT and high-speed connections with 5G is increasing dramatically. Many regulated aspects such as intercarrier automation, mobile roaming settlement, identity, and mobile payments could benefit from the speed and transparency of blockchain. Specific blockchain solutions for IoT also offers opportunities in the smart city context.
Finance	The financial sector is the sector most impacted by blockchain technology. The concept of blockchain was brought to the forefront with the cryptocurrency, Bitcoin. It is also understandable that economic issues have continued to be the motor behind many of the developments of the most crucial blockchain products and services in society today. The cryptocurrencies enable the transfer of money in real time without any intermediaries. Initial coin offering (ICO) models facilitate the initial financing of business without the intervention of any bank. Additionally, token economies enable the building of entirely new economic ecosystems outside the traditional financial markets. Smart cities initiatives using blockchain could impact financial inclusion, settlement management, as well as fees management. These blockchain technologies for finance are being utilized in the city of Dubai.

Despite the high relevance and potential of blockchain technology applications in smart cities, the concrete literature reporting blockchain use-cases in cities remains scarce.[54] In the following sub-sections, we will be exploring ongoing projects on blockchain for cities and underscore use-cases to be able to provide insights to the city managers, who are seeking guidance on the topic.

4.2 Blockchain for cities' use-cases

Several cities around the world in Australia, Estonia, Malta, China, Denmark, Switzerland, the United Arab Emirates, Georgia, Ghana, Honduras, Singapore, the United States, the United Kingdom, Sweden and others are planning, initiating, developing or currently running blockchain-based initiatives. Dubai has been championing blockchain for their city by developing related projects and creating a common platform to make the city paperless. The Swiss city of Zug has the ambition to become the "Crypto-Valley" by providing a "crypto-friendly business ecosystem". The city of New York is launching several blockchain-based initiatives and working in collaboration with the government, universities and citizen stakeholders to build a flexible, enabling regulatory environment and serve as a hub or resource Big data for the city's blockchain industry.

For the preparation of this report, data from 13 cases were collected. Based on the available data, this report documents eight use-cases linked to blockchain for cities, to better understand the transformative potential of the technology for building a smarter and sustainable city. The ensuing subsections describe the cases of the debt relief in the city of The Hague, the Decode and decide projects in Barcelona and Amsterdam; the energy system management in South Holland; Moscow weekend fairs; the Moscow Active Citizen project; the land registry in Georgia and the cell tower voting system in South Tyrol.

Case 1. Facilitating Debt Relief in The Hague

The Dutch Central Judicial Debt Collection Agency (CJIB) looked into solutions for better sharing and analysis of data about people in debt among government agencies, without compromising the people's privacy. Several issues prompted this initiative.

It is noted that there is a problem of widespread and spiraling household debt. Some 1.4 million Dutch households have debt problems or are at risk of plunging into debt.[55] Minor issues related to an unpaid parking ticket may have serious consequences for people already in debt. Unpaid fines are automatically increased by the CJIB, who are also authorized to collect debts directly from the bank accounts of citizens. This can set off a chain reaction of costly measures, which can result in imprisonment and sometimes even in destitution and homelessness. This can also be very expensive for the state: a report showed that resolving a EUR 14 000 debt could cost Dutch society as much as EUR 269 000.[56] In this scenario, preventing debt makes financial sense for society as a whole. Debt resolution involves a complex system of actors with uncertainty about privacy-related issues. A person in debt might be in a city's financial help programme; however, in many cases, debt collectors are not aware of their position. While both are government agencies, they are separate, with distinct registers of individuals. Often, these entities are reluctant to share personal information for fear of compromising privacy and violating privacy regulations. The same situation occurs in services such as immigration and healthcare, where personal information plays a pivotal role. Such agencies rely on self-verified data and rarely attempt to gather additional information in order to obtain the full picture.

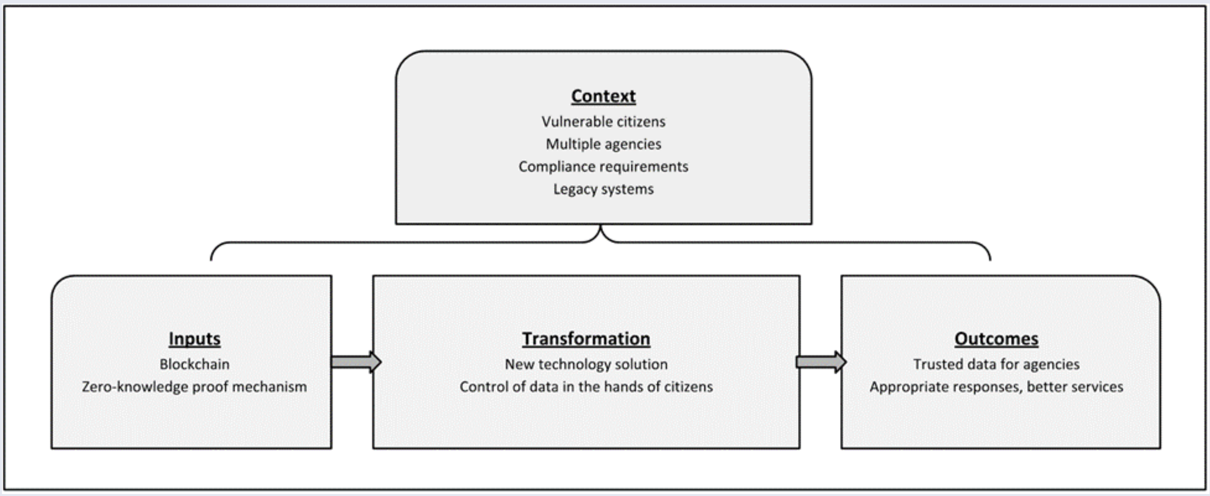
More generally, there is the problem of limited control over personal digital information. Companies benefit from tracking and storing information about individuals, often without their knowledge.[57] Ideally, where data cannot be aggregated and anonymized in particular, individuals should have control and ownership of their personal digital individual data (where possible). Moreover, some 1.1 billion people worldwide lack any form of formal identification (World Economic Forum, 2018)[58] and consequently struggle to access basic services such as healthcare, education or credit. The Hague, as the international city of peace and justice, wants to build an infrastructure for digital identity that can be benefitted from globally in the future.

In addition to these issues, there have been two motions filed in the Dutch House of Representatives[59] that relate to this project, and the National Ombudsman (2019)[60] has also argued for better measures for the fair collection of debt in the Netherlands.

There have been two successive phases of the project; a third is under development and two more are planned. The first phase involved analyzing the problem, examining potential solutions, and building the core ecosystem. The project is a collaboration between the CJIB, the Dutch Blockchain Coalition, Ledger Leopard (development), Delft University of Technology and CMS firm lawyers.

The second phase included the technical development of a privacy-by-design tool that allows individuals to share information on their debt assistance from another agency with the CJIB, without revealing any further details.

Figure 6: Smart cities dimensions of the debt relief initiative in The Hague



The tool combines a public-permissioned blockchain and zero-knowledge proof cryptography. The solution uses open-source technology from the Sovrin Foundation (2019),[61] which provides a decentralized identifier for verifiable, self-sovereign digital identity (W3C, 2019). The tool was tested by Delft University of Technology to prove that it is secure, and the lawyers of CMS have determined that the tool is compliant with Dutch and European law. All results have been publicly reported by CJIB. In the third phase, the tool will be tested. Currently, The Hague is fundraising for phase 3 and examining how to embed the tool in the operations of the debt collection agency. Challenges for this phase are:

1. to design the user experience (UX) and user interface (UI), taking into account the vulnerability of the target group; and
2. to connect the prototype to existing systems, which might be different for every city, while aligning to national digital identity initiatives such as MijnOverheid[62], DigiD[63] and De Blauwe Knop[64].

While this solution is being developed specifically for the case of debt collection, it is also applicable to other situations where individuals need to make verifiable claims about themselves on a network of related, but sparsely connected actors that, by law, cannot share personal information. This means that the solution has the potential to impact other areas of government service delivery, including youth, migration and digital participation.

This case demonstrates the use of smart technology to contribute to the areas of smart governance and smart people. As input, the intervention makes use of blockchain and zero-knowledge proof cryptography.[b] [65] The transformation that is facilitated includes developing a new technology solution that allows individuals to share data with other agencies. Agencies are also able to utilize the assigned data for the defined purpose without violating privacy laws. The solution is easily integrated with existing legacy systems. The intervention allows agencies access to trusted information about individuals that other agencies hold, without needing to share these data. This allows agencies to provide more appropriate cost-effective services to individuals that take account of their personal circumstances, making the overall process less traumatic.

All this takes place in a context in which vulnerable citizens obtain services from multiple agencies that are not allowed to share personal data among them. The solution needs to be easy to implement and to integrate with existing legacy systems. Within this use-case, there are multiple actors that are not connected and do not necessarily trust each other. Under these circumstances, it is necessary to remove the intermediaries.

The main asset is digital and requires maintaining a permanent record of the information about the debt; however, it is not necessary to keep the sensitive and personal data as well as any other volume of non-transactional data. Even though the users here are known, the control by the CJIB is required and there is no need to implement a contractual relationship to share the access. The proposed solution is looking to contribute to economic, as well as social sustainability by improving financial inclusion.

Lessons learned and conclusions:

- Blockchain technology allows for self-sovereign identity management and verification of owner-shared data without compromising privacy.
- There appear to be promising technical solutions that can give individuals control of their personal data, comply with privacy laws and allow for data sharing that will improve government services.

Based on the technical properties required, blockchain is a suitable technology but not necessarily the most relevant in this context. Some of the challenges and opportunities of blockchain for this case-study have been elaborated on below.

[b] Zero-knowledge proof in the context of cryptography is a special algorithm for identity verification (IEEE, 2010).

Opportunities	Challenges
• A solution has been developed that appears to address the technical, legal and individual requirements for privacy and data sharing between government agencies. • This solution allows the individuals to control their personal data and to communicate what they choose to reveal between government agencies. The zero-knowledge proof validates the information without passing on any details. • The problem of sharing sensitive data between government agencies is widespread. A solution that addresses this effectively could lead to improvements in many public services. • Blockchain is an appropriate technology for this solution because it is decentralized; hence no one actor has control of the data. Individuals have control of their data and there is no single point of failure. • This solution offers the potential for people without formal identities to gain them, and thus gain access to the government (and private) services.	• It is difficult to innovate effectively, especially with the target group in mind. People in debt are often not comfortable with high-tech solutions; therefore, a careful co-design process is needed to ensure that the solution will meet their needs. • There is also a risk that this project will not be accepted by the 'identity' ecosystem because it would mean a significant shift in the way identity is dealt with. Self-sovereign identity is a new idea; hence it may be difficult to get people on board to scale-up the solution. • A single implementation partner and/or technology raises questions about technology lock-in, which should be avoided. Hence, the project is also looking for a way to allow multiple parties and solutions to join in the decentralized identity ecosystem. • "Zero-knowledge proof" is not yet mature. Currently, they are the subject of scientific research articles and not completely implemented or existing implementations are limited.

Case 2. Allowing young people to verify their age in Amsterdam

When personal data need to be verified, one of the challenges is to do this in a manner that reveals as little as possible about the individual. The *Claim Verification 18+* is a prototype application that enables people to prove that they are over 18 years old, without revealing their name, date of birth or other information. Such an app could be used to gain access to a club or to buy alcohol.

The goals of this pilot project were to:

a. develop a useful app;

b. improve understanding of the user experience and journey;

c. give people control over their personal data; and

d. test out the capability of the DECODE tools (which are described below).

The Passport Box piloted a system for people to prove that they are over a certain age, for example, over 18, without having to share their full identity, date of birth, or social security number, through the use of attribute-based credentials. Claim Verification 18+ consists of a mobile app and a passport scanner.[66] The passport scanner is a physical box that scans the RFID in a passport and records information about the individual. This process needs to be completed just once. The app then allows the supplier, who needs the information verified, to pose a question to the individual on their phone with an accompanying QR code. The individual can scan this code with their phone and choose whether or not to have the app answer the question.

To this end, the app is answering a question such as “Are you 18 or older?” with a simple Yes or No. It does not need to reveal what the actual age of the individual is, or their date of birth. This is known as a data minimizing authentication mechanism.

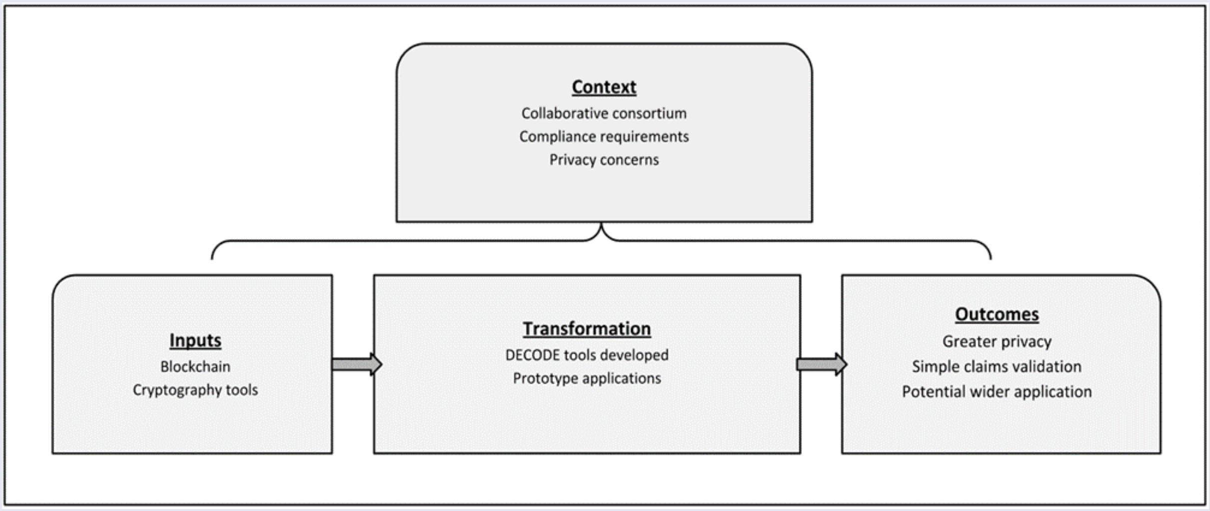
The system was tested during 2018 and 2019; and based on the results, the city of Amsterdam has decided to develop an app called Stadspas (City pass) to facilitate access to city services as part of the “Open City” programme.[67]

The Claim Verification 18+ prototype is based on the technologies developed by the DEcentralized Citizens Owned Data Ecosystem (DECODE) project, which is a three-year project funded by the European Commission, involving 14 consortium members.

This project has been developing tools that give people control of their data using “entitlements” attached to private data. It uses blockchain technology and cryptography to develop software tools for managing personal data, while also investigating data governance models to better understand how data can be shared for economic benefit.

The backbone of the DECODE platform is Zenroom, a “process virtual machine” that implements zero-knowledge proof authentication and attributes-based credentials.[68] Zenroom was used as the basis for all the DECODE prototype systems.

Figure 7: Smart cities dimensions of the DECODE Claim Verification 18+



DECODE has implemented a distributed ledger (or blockchain) technology that integrates with the Zenroom virtual machine. The blockchain is used to delegate the verification of claims to a decentralized peer network. Blockchain technology enables this to take place in a decentralized and secure (immutable) manner, rather than by a central authority. In this way, trust is vested in the technology rather than in the central authority.

DECODE makes use of the Sawtooth implementation[69] which is free software from the Hyperledger consortium coordinated by the Linux Foundation. This blockchain is simple and modular, and provides well-documented software development tools. Sawtooth does not require the use of a particular virtual machine or consensus algorithm, allowing the solutions developed in DECODE to be independent of any particular blockchain and portable across platforms.

For *Claim Verification 18+*, the passport box scans a passport and authenticates the contents, including the photo. It then uses Zenroom to encode the information and store it on blockchain.

Although the blockchain component turned out not to be strictly necessary for this prototype, it will form part of subsequent full-function systems.[70]

The range of attributes that can be verified was limited in the prototype applications; however, it is possible to use the same technology to verify a wide range of attributes in a way that leaves individuals in control of their data. The city of Amsterdam is continuing the project (renamed Anonymous Proof of ID) with improvements to the interface and interaction model, as well as proof of driving ability.[71] Future developments may include research into a system of credentials for undocumented citizens.

This case demonstrates the use of smart technology to contribute to the areas of smart governance and smart people. As input, the intervention makes use of blockchain and cryptography technologies. The transformation that is facilitated includes the development of the DECODE tools, a generic set of tools to facilitate better handling of personal data. In addition, prototype applications were developed, including Claim Verification 18+.

The outcomes of the intervention, once fully developed, will be an application that provides a simple, reliable way to verify claims while ensuring greater privacy, as individuals do not need to reveal personal data. There is the potential for providing new services and improving the processes surrounding existing services, which include claim verification. All this takes place in the context of a large, funded, collaborative consortium, which has been set up in the face of concerns about increasing privacy risks and the need for compliance with a range of regulations. It is expected to contribute positively to social sustainability.

Even though the users of the system are not known, and it is essential to work with digital assets, it is not clear whether the relationships between the entities and the users are based on trust or not.

It is also not determined if it is critical to remove the intermediaries or whether a permanent record of the data is required along with writing access. While centralized control of the system is required, it is not necessary to implement a contractual relationship and it is essential to store sensitive data. With these specificities, blockchain might be a relevant, but unsuitable technology.

However, further exploring blockchain technologies remains a good opportunity because the DECODE tools being developed provide a basis for developing a range of solutions, linked to principles of individual ownership of personal data, decentralization and flexibility in terms of the underlying technologies.

Lessons learned and conclusions

- It is possible to use blockchain with zero-knowledge proof and attributes-based credentials to prove claims with limited exposure of personal data.
- Prototypes can be used to illustrate the technology's capabilities and are useful for understanding the potential applications in cities.
- Instead of approaching technology in terms of "I want it to work" or "it has to be easy", there has been a perspective shift on technology, architecture, and how that relates to power, ownership, agency and privacy. Concepts including zero-knowledge proof, and encryption (and their importance) all need to be better understood.
- A policy document has been developed to inform policymakers and provide them with recommendations in the fields of privacy and digital identity.

Case 3. Digital democracy and data commons, Barcelona

The Digital Democracy and Data Commons (DDDC) project is another pilot implementation of the DEcentralised Citizens Owned Data Ecosystem (DECODE) tools and governance models for managing personal data (described in the Claim verification 18+). DDDC, based in Barcelona, sought to test out the process of integrating the DECODE tools into the DEcidim system, an existing participatory democracy platform. DEcidim was created by the city of Barcelona and is currently used by 60 000 people. It has also been implemented in dozens of cities near Barcelona and beyond the Spanish borders.

DEcidim had a recurring issue. On the one hand, it needed to accept and count votes on petitions anonymously such that there is no way to connect individuals with the votes they cast. On the other hand, it needed to ensure that the people voting were eligible to vote such that results can be legally binding. It was also essential to secure the confidence of users. Knowing the demographics of users would also assist in mapping city problems and understanding who uses the system.

The DECODE tools provide a way around this problem by separating the verification of the voter from the process of casting and recording a vote. DECODE tools were combined with DEcidim to create the DDDC system.

The new DDDC system provides a website that verified participants can use to identify petitions that are of interest to them. The user is verified by an external credential issuer who checks their credentials and loads a signed verified ID attribute into an app on their mobile device. These data are not shared with DDDC. Each petition includes an overview of the issue and (optionally) a request for personal data.

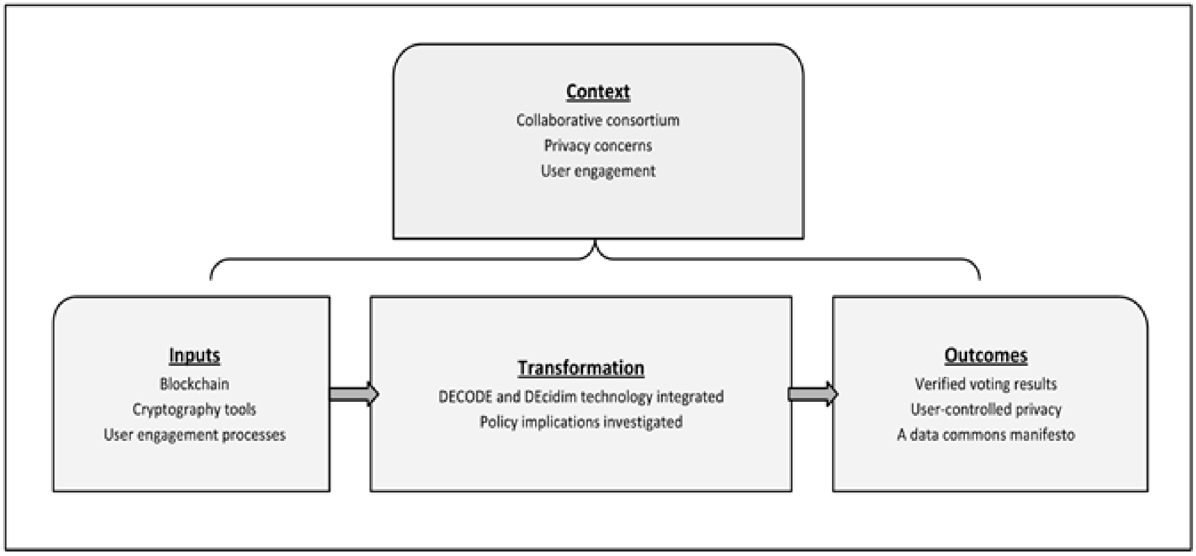
The user can choose to share anonymized data such as the age range or neighborhood of residence. The user signs the petition with a secured Yes or No vote. Any attributes to be shared are cryptographically combined with a unique identifier related to the petition and submitted to a blockchain ledger as a transaction.

The DDDC system then has real-time data about how many votes have been cast that cannot be associated with the voter. The cryptographic validations ensure that only verified residents have voted and that each vote is valid. DEcidim deals only with the results of the petition which are decrypted when each petition is closed. Aggregated, anonymized results are made available via the Barcelona Now dashboard (BCNNow) which uses data from DEcidim and the blockchain ledger. The blockchain ledger effectively becomes a permanent and tamper-proof data common with anonymized datasets that could be used to detect city problems.

The system makes use of DECODE's Zenroom, privacy enhancing technologies (PETs), the Chainspace distributed ledger, and the Coconut attribute-based credential scheme. The DECODE Wallet functions allow users to consciously choose whether or not to share elements of their personal data for analysis. Not even the administrators of the system have any access to information about user identities or how they voted.

This pilot has shown that the DECODE technology can support that of DEcidim and their vision of participatory democracy. The data commons element has included debates and workshops around data policies and the potential uses of a data commons for public good. This supports the goals of the DECODE project to advance citizen-centric data governance and a more democratic digital economy[72]

Figure 8: Smart cities dimensions of the DECODE



The DDDC pilot had three goals. The first was to integrate the DECODE technology with DEcidim to address the tension between voter validation and vote anonymity. The second was to deliberate data regulation and governance in the context of the new digital economy, specifically to promote user control of personal data. The third objective was to construct and experiment with data commons to improve the participatory process itself.

During the project, various workshops and user-experience sessions were held to share information about the pilot and to solicit feedback from users, including explorations of the policy implications for cities and states, as well as potential uses of the data common. Some of this was done using the DDDC tool itself. Feedback showed that some people felt that the system was coherent and valuable, while others were concerned that it was complex and difficult to understand. Work on the tool and with city communities, is ongoing.[73]

This case demonstrates the use of a smart technology to contribute to the areas of smart governance and smart people. As input, the intervention makes use of blockchain and cryptography technologies, as well as a variety of user engagement processes. The transformation that is facilitated includes the technical integration of the DECODE tools into the DEcidim system, as well as processes to interrogate policy implications and make recommendations for data sovereignty.

The outcomes of the intervention include a technical solution to the challenge that DEcidim had verified along with anonymous voting, giving users control of their personal data. The pilot also led to data common of anonymized information about how people in the city vote on petitions that could be used for the public good, as well as a data commons manifesto.

This use-case involves multiple actors. There is no trust relationship between the city of Barcelona and its users. As in any participatory voting system, the users are not known. There is no need to centralize the control of the system at the city of Barcelona or any other entity. It is essential for the voting system to remove the intermediaries. The permanent record is necessary for verification purposes. However, there is no need to keep the non-transactional record of the information. It is essential to share the writing access with all the users. In this context, there is no information related to: (a) the necessity to work with digital assets or (b) highlight the importance of high-performance systems to validate the transaction.

Additionally, there is no need to implement a contractual relationship along with the necessity to store sensitive data. This project is also relevant for improving social sustainability.

The pilot project took place in the context of a large, funded, collaborative consortium, engaging with other partners to address growing privacy concerns. The project benefitted from engaged individuals who committed their time and energy to the process.

Lessons learned and conclusions

- Distributed ledgers (blockchain) can be used to make public voting (petitions) systems that are auditable, fast and secure.
- Such systems allow users to choose which of their personal data they wish to withhold and which they would like to share, in order to allow platform managers to understand their user base.
- Users have been able to understand and use the petition (voting) system, without having technical expertise.
- The process is GDPR (General Data Protection Regulation)[74] compliant according to the data protection authority at the city council of Barcelona.
- There has been a shift in perspective towards the need to better understand how technology relates to power, ownership, agency and privacy.
- Based on the assessment of the project properties, blockchain technology seems to be partially suitable.
- In the assessment of the project properties, blockchain technology seems to be partially suitable.

It does not apply to the processing of personal data of deceased persons or of legal persons. The rules do not apply to data processed by an individual for purely personal reasons or for activities carried out at home, provided there is no connection to a professional or commercial activity. When an individual uses personal data outside the personal sphere, for socio-cultural or financial activities, for example, then the data protection law has to be respected (European Commission, 2020).

[c] Regulation (EU) 2016/679 of the European Parliament and of the Council1, the European Union's ('EU') new General Data Protection Regulation ('GDPR'), regulates the processing by an individual, a company or an organization of personal data relating to individuals in the EU.

Opportunities	Challenges
• DECODE has had an impact on the data governance policies of Barcelona, particularly the city's "ethical digital standards" and the "data sovereignty" procurement clauses.[75] • The data sovereignty clauses have become the reference standard for the Cities Coalition for Digital Rights, a global alliance supported by the United Nations, United Cities and Local Governments (UCLG) (an international umbrella international organization for cities, local and regional governments, and municipal associations) and Eurocities.	• The consortium continued to work on technology research throughout the process. Some technology features which were developed at a later stage were not ready to be tested during this pilot. • The project experienced some disruption when planned events had to be postponed or cancelled due to the electoral calendar at the City Council, which resulted in periodic publicity restrictions according to the local legislation.

Case 4. Energy system in South Holland

Most energy systems are designed using a centralized model. A power plant feeds energy into the system which is transformed into smaller voltages for use by homes and businesses. Currently, there is a decentralized influx of renewable energy sources into this system. While these initiatives are necessary for long-term sustainability, current grids were not designed for this type of energy supply. It becomes difficult to balance supply and demand in the system, and endangers the stability, reliability and safety of these grids. The investments required to make grids cope with the changes are immense: electricity lines need to be enlarged, substations replaced, and facilities installed to manage congestion, including storage capacity for supply peaks.[76]

An innovative collaborative research project in the form of a "living lab" is investigating how blockchain-based energy systems (among other innovations) can be deployed to enable wide participation in the energy system without costly upgrades to the current grid. Partners in this research include citizen energy cooperation, De Groene Mient & Warm in de Wijk, the province of South Holland, the local (public) energy distribution company (Stedin), energy company Joulz, GridSingularity, The Hague University of Applied Sciences, 4TU Research Data and the energy transition department of the city of The Hague.

If local energy networks can balance out their demand and supply patterns, less investment is required in updating existing grids. The smallest energy entity that can be balanced is a household, with appliances using energy and batteries to store it. If an imbalance exists, the household could tap into a neighborhood energy community, where a new balance is sought. If the neighborhood is not in balance, a city-wide energy exchange could be activated and so on, potentially to the size of countries.

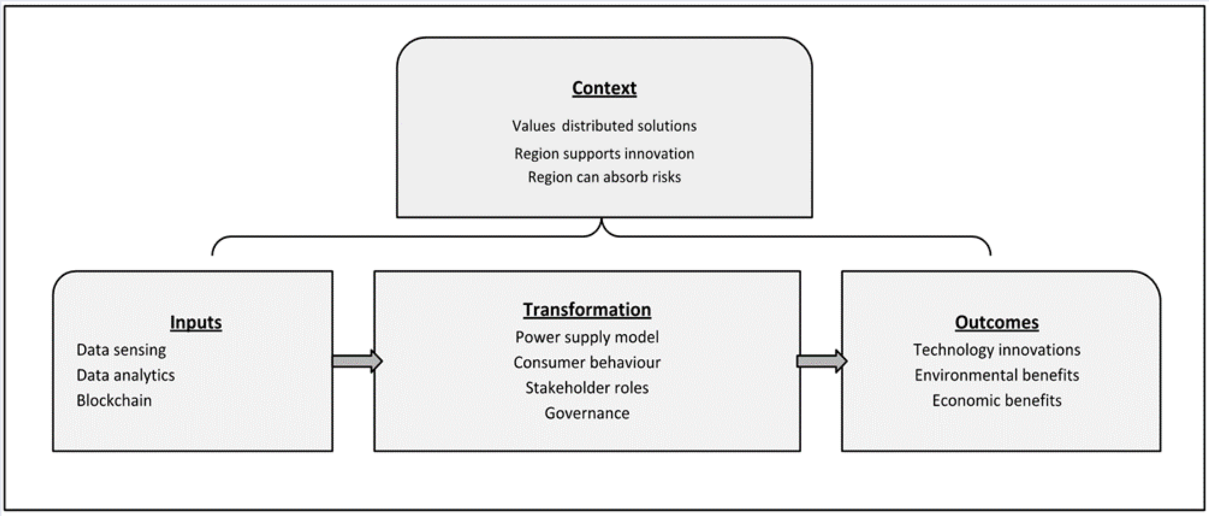
Local balancing is possible if peer-to-peer sharing of energy can happen across these different energy communities, creating a fractal grid that can operate at many different scales.[77]

Blockchain technology promises to facilitate localized balancing in energy grids through smart contracts that are activated at specified values of parameters like energy price, available storage capacity, forecasts of supply and demand or other factors. This arrangement also allows peer-to-peer trading of power. Technology to facilitate this process is being designed by the Energy Web Foundation.

Thus far, the project has designed and constructed eco-friendly houses that are well isolated and use solar power to be 90 per cent independent of the grid. Community energy data from 2018 have been collected, analyzed and used to simulate local energy systems. The data showed that benefits were possible using localized balancing through blockchain-based transaction models and optimization schemes. The connection with the central grid could be scaled down, reducing costs, particularly with the addition of neighborhood batteries.

To collect more detailed data to understand energy behaviour and inform the technical design of the smart grid, infrastructure is being installed that allows for measurements of energy flows every 10 seconds. Direct neighbors (70 households) are being asked to contribute their energy data for analysis. These data will facilitate the design of specific control mechanisms for individual devices, batteries and other grid elements, including a peer-to-peer energy trading platform. All information and designs will be given open access status, such that they can be used by other initiatives.

Figure 9: Smart cities dimension energy system in South Holland



Official exemption from the Dutch electricity law of 1998 has been granted to facilitate experimenting towards a "smart multicommodity grid". In 2019, the consortium was granted the status of "large experiment" by the Dutch Enterprise Agency, which means that the project can scale-up to 10 000 households.

In the future, new energy cooperation is planned that will start using the local grid in 2023, scaling up to 300 households. It will make use of the real-time simulations of the energy network, and automated transactions facilitated by the blockchain-based smart contracts. Fluctuating energy prices will be reflected in a flexible tariff and payment system. There is also the intention to use electric vehicles as batteries to help balance the system with bi-directional charging and discharging. Based on the current plan, the grid will be scaled-up to 3 000 households. The researchers hope that this case will demonstrate how existing centralized electricity grids can be turned into transactive grids, allowing for a greater and more flexible use of renewable resources.[78]

While this research is specifically concerned with improvements to existing energy grids, the same concepts can also be applied where no central grid or electricity company is currently present.

This would result in self-organizing and self-balancing grids, or microgrids, such as those proposed by organizations like Energy Bazaar. This case demonstrates the use of smart technologies to contribute to the areas of smart economy, smart environment and smart living. The intervention makes use of data sensing to understand the behaviour and monitor demand, data analytics to predict behaviour and demand, and blockchain to manage load balancing.

The transformation that is facilitated includes changes to the roles of stakeholders, with households and communities playing a more active role in the energy grid, as opposed to being mere consumers in the existing centralized grids. The case also illustrates the need for changes in the governance of energy grids to allow for the new approach. The choice of blockchain technology was based on the:

a. absence of trust between entities and the users of the system;
b. need to remove the intermediaries, the necessity to work digital assets;
c. need to maintain a permanent record and the implementation of a contractual relationship; and
d. need to share the writing access.

However, the users are known, and the system requires to be centrally controlled, which raises some questions.

The outcomes of the intervention include environmental benefits as more renewable energy sources can be incorporated into grids, and to the economy, as power supply costs can reduce, and supply could become more efficient.

Better information at the household level enables smarter living as greater awareness of energy use enables individuals to modify their behaviour accordingly. All this takes place in a context in which distributed and multi-scale solutions are increasingly valued. The intervention is facilitated by being in a geographical area where there is political and financial support for the project, despite risks and challenges.

Lessons learned

This project depends on the buy-in of the community and their willingness to share data.

- The broad composition of the consortium allows for a strong and resilient partnership that can withstand some setbacks.
- The success of the project depends on a legal and political context that is supportive. The researchers have navigated these barriers because the work is experimental; however, it would still not be permitted within the normal regulations of the Netherlands. Implementing the solution in other countries is likely to face similar challenges.

As a consequence of the experimental nature of the project, results will only emerge in the long term, and the project requires ongoing support and commitment to reach that point.

Opportunities	Challenges
• Currently, the initiative is an experiment and this status will end after 10 years. If sufficient progress has not been made on the legal and political aspects of implementing these kinds of solutions, the future of the concept is uncertain. • Much of the technology is still under development, and will only be fully tested by 2030.	• The project represents an opportunity to expand the sources of energy for the grid, to include a more environmentally sound option, while reducing the costs of adapting existing grids to have this capability. • Blockchain introduces the opportunity for using smart contracts to trade in energy at the level of a household, community or city. • The model that is being used to create virtual energy communities is highly scalable. It can be applied to any energy network where sufficient data on the nodes can be measured, and the loads can be controlled or scheduled.

Case 5. Moscow weekend fairs

While smart cities use technology to make the everyday life of residents easier and more comfortable, not everything "smart" is about gadgets and robots. One of the most important urban challenges is to bring high-quality products and food to people. Since 2011, weekend fairs in Moscow have provided city residents with high-quality food and agricultural products, while supporting local producers and entrepreneurs. This works well; however, a shortage of available trading sites at the fairs has caused arguments between providers and led to mistrust of the fair organizers.

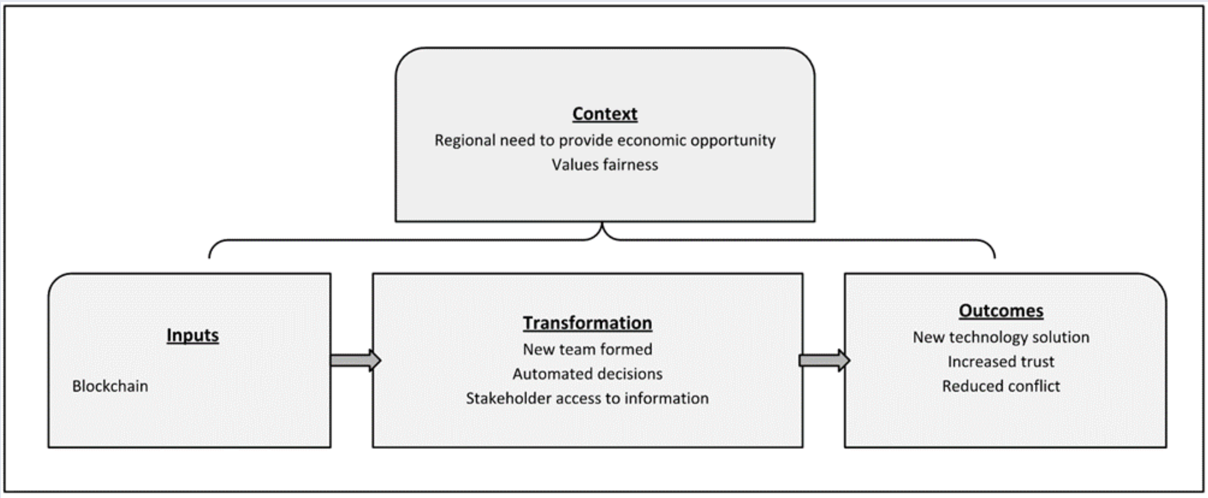
In order to attract more direct manufacturers from Russian regions and to increase access that residents have to goods, trading sites at weekend fairs are free.

Twenty-four days before each trading season, application campaigns are conducted and individuals, farms and other producers have fifteen days to submit electronic applications to participate.

About 15 000 trading sites are available, however, around 20 000 applications are received for each season, meaning that many do not get a place.

Since the summer of 2018, the Moscow government has introduced an Ethereum-based, private blockchain solution to increase the transparency in the allocation of trading sites. Applications are now duplicated on the blockchain and timestamped. Allocation of sites is based on time of submission, other things being equal, and the solution uses smart contracts to compare applications. The records are then updated depending on whether or not applicants have been allowed to take a site.[79]

Figure 10: Smart cities dimension for the Moscow fair



All applications are recorded in real time and the blockchain ensures that no one can make changes to the applications or the allocation decisions. Previously, the applications could only be viewed by government agencies; however, the data from the blockchain can be now accessed by anyone who wants to check the records. (The software can be downloaded and installed on any computer.) The decisions are accessible to anyone who can use the technology to see them, leaving applicants in no doubt about the results and the fairness of the process.

The new system has reduced suspicion and mistrust in the departments that organize the fairs. Fair participants have commented positively on the new system. Even those who initially considered blockchain complicated, have been able to understand the process and access the information. Hence, once of the positive outcomes of the system has been to expose residents to new technologies. The result is a trustworthy system that has increased transparency and satisfaction. The system was developed by a special team assembled for the project. This team has developed skills and collected evidence of the success of this project for creating a good basis to implement blockchain technology to improve other city services.

This case demonstrates the use of smart technology to contribute to the areas of smart governance and smart economy. As input, the intervention makes use of blockchain to make decisions pertaining to the allocation of sites transparent. The necessity to maintain a permanent record, and the requirement of the system to share the writing access, have been justified by the processing of digital assets.

The transformation that is facilitated includes automating the comparison of applications using smart contracts and providing the applicants with transparent information about the allocation of sites. This case also included a new approach to developing the system using a specially assembled team.

The outcomes of the intervention include the new technology solution, as well as the benefits of increased trust and reduced conflict over the allocation of trading sites. All this takes place in a context in which there is a need for economic opportunity that coincides with a demand for food and other products. The intervention is supported by the values of fairness and transparency.

The project has resulted in a team with the skills to develop blockchain solutions and has proved that such systems can be useful. This opens up the possibility of creating similar solutions for other city challenges.

Lesson learned

- Is the solution appropriate for another context inside a smart, sustainable city?
- It is important to highlight regulations and ethical issues beyond the technology the social aspects.
- There is a certain level of trust between the users and the city. In this scenario, enhanced transparency could be afforded by blockchain technology to convince people that processes in government are being applied fairly.
- Blockchain technology can be understood and used by city residents.
- The success of the project depends on being able to assemble a team of suitably skilled technical staff.

Case 6. Active Citizen

Many cities have already implemented or are starting to implement platforms for residents' participation in urban life and two-way communication with local government. Such platforms seek the opinions of residents through voting systems or problem-reporting mechanisms; however, many of them encounter low levels of trust. People doubt that their view has weight and will be heard, or they suspect that the voting results are faked.[80]

This was the situation in Moscow where the Active Citizen system was developed to allow people of different ages and professions to participate in the positive transformation of their constantly growing and changing city.

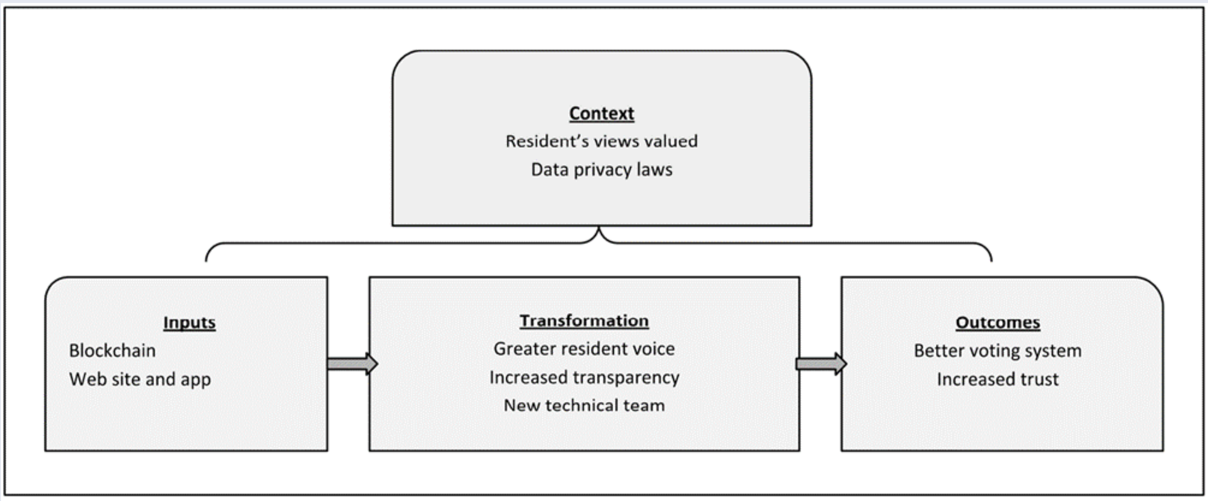
Active Citizen (AC) is an online referendum system, accessed through a website and mobile application that allows residents to vote on matters of city development such as speed limits, new playgrounds or parks, sports complexes, additional bus routes, lawn mowing, the naming of the new metro ring and much more.

To encourage participation, the system awards points that can be redeemed for brand souvenirs or tickets to theatres or museums. Through these referendums, residents are able to play a greater role in influencing the policies of their city.

To date, more than 4 000 voting sessions have been held and over 100 million opinions gathered from 2.2 million participants. The Moscow City government wants to ensure that every Active Citizen participant feels certain that his or her opinion counts. Therefore, to increase transparency and accountability, the Active Citizen project began to use blockchain technology.

The project started in 2014 with a simple web and application system. Voting was city-wide and accessible to all registered participants. However, people believed that the city influenced the results. Residents did not understand how the votes were recorded and the results calculated. These processes took place in a physically and digitally protected data processing centre. There was no technical tool to make the counting of votes visible – until the advent of blockchain.[81]

Figure 11: Smart City dimension of Active Citizen



In 2017, Active Citizen became the first IT project in the Moscow City government to switch to blockchain technology. A specially assembled team in the Department of IT developed the system using a private blockchain on the Ethereum platform. The system makes use of a proof-of-authority consensus algorithm, the Parity platform shell and the Solidity programming language. Since then, there have been ongoing improvements to the system's security and efficiency.

There were some difficulties. For example, the means to protect personal data which, according to Federal law, cannot be made visible to the public. The solution was to replace personal data with a user ID, which is stored in the system and the blockchain. In this way, the individual can always find his or her user ID and voting record, without disclosing any personal data. Anyone who voted can verify that their vote has not been changed, either on the Active Citizen website or by installing a node on their computer.

The blockchain makes voting in Active Citizen transparent and allows anyone to check the results and see how the votes of residents are counted. As a result, people understand the process better and trust the results. The blockchain-based solution has created the necessary conditions for increasing confidence in the Active Citizen project and in public services more generally.

This case demonstrates the use of smart technology to contribute to the areas of smart governance and smart people.

As input, the intervention makes use of a web site and mobile app and then uses blockchain technology to make the votes immutable and transparent. The transformation that was needed for this change included a shift in resident participation in city decisions, and more accessible information for residents to improve transparency. There were also changes in the approach to IT projects with dedicated team-building skills in blockchain technologies.

This system improved the existing participation based on justified use of blockchain technology where there is no direct trust between the entity and the citizen. Moreover, there is no need to have a distinct entity controlling the system. There is also a requirement to keep a permanent record, as well as shared writing access. However, there is no specific need to remove the intermediaries, or the digital assets. Beyond these properties, the Active Citizen case does not require the implementation of a contractual relationship. Finally, the system must be able to store a large volume of non-transactional data.

The intervention resulted in a new system that was more secure and efficient. The benefits have included increased participation in city decisions by residents and greater trust in the system and the public services. All this takes place in a context in which the views of residents are valued. There are also legal considerations that the system has had to take into account.

Lesson learned

- Blockchain technology creates the necessary conditions for increasing confidence in public services through immutability and transparency.
- Data privacy concerns that result from the transparency of blockchain can be dealt with by using identifiers and storing personal data in a parallel system.

Opportunities	Challenges
• The blockchain characteristics of immutability and transparency increase trust in public engagement systems. • Blockchain technology makes it possible to make large data arrays publicly available and verifiable in a manner that other technologies cannot. This opens up future prospects for public services.	• One of the main challenges is using blockchain for data verification and transparency while not making personal data public.

Case 7. A land registry for Georgia

Land is one of the fundamental attributes of a city; however, there are serious issues with the ownership of land across the world. In 2017, nearly 70 per cent of the world's population lacked a "legally registered title to their land",[82] and in 2015, "land and environmental defenders were being killed at a rate of more than three a week".[83] Land disputes directly affect the growth of smart and sustainable cities because:[84]

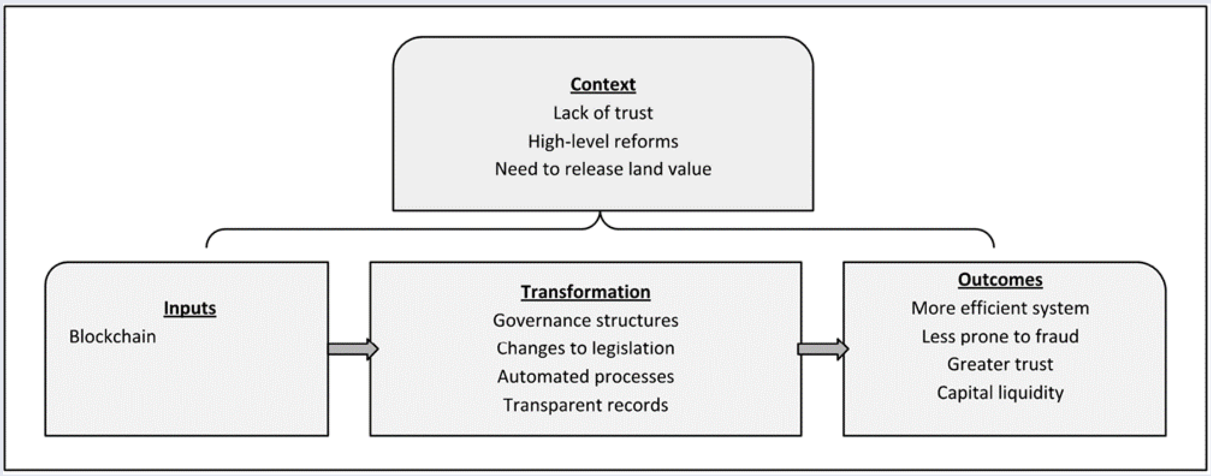
1. Without a defined and transparent process for land title management, governance of property rights becomes a challenge and corruption could occur.
2. Economic growth is stifled because land cannot be used as collateral for loans or transactions, and it is difficult to divide large plots of land into smaller plots, creating "dead capital".

The Republic of Georgia has a history of poor governance such that people do not trust the bureaucracy or politicians. Maintaining the land registry was the task of two agencies – the Bureau of Technical Inventory and the State Department of Land Management – with overlapping functions.[85] The lack of transparency bred corruption as records could be changed without tracking.

In the mid-2000s, President Mikheil Saakashvili launched a series of reforms to reduce bureaucracy and increase transparency. In 2004, the National Agency of the Public Registry (NAPR) replaced the two agencies and legislative reforms simplified the property registration process. A land registry database was created, including property titles and satellite photographs. This was a step forward; however, it did not address the lack of transparency or trust because records could still be changed by government employees and it was difficult to hold anyone accountable for data manipulation.[86]

Starting in 2016, the NAPR and the Bitfury Group developed a blockchain-based land registry. The custom-designed, private, permissioned blockchain is implemented on the Bitcoin blockchain. To minimize the data written to the blockchain and to ensure privacy, full details of ownership are stored in the NAPR database and not on the blockchain. A distributed digital timestamping service allows NAPR to verify and authorize the essential information about the citizen and the property, establishing proof of ownership. The NAPR also provides an application programming interface (API) and guidelines for stakeholders who want to use it to verify the data.

Figure 12: A land registry for Georgia



As of 2018, 1.5 million land titles were published on the blockchain-based registry. The new system reduced operational costs by 90 per cent and reduced the time to register property from three days to ten minutes, eliminating the need for legal professionals in the process. The Republic of Georgia has since been named one of the top three countries for ease of property registration, as well as a top 20 country for ease of conducting business, in the World Bank's "Doing Business" survey.

Blockchain removed the trust problem through transparency. While officials can make changes, they are immediately visible. The smart contract system needs no human intervention; hence people are being asked to trust the system rather than the official. The new system helps Georgia to secure the national boundaries too, since, with reliable records, encroachment can be defended through an international legal claim.

The next phase of the project is to make properties more "liquid" by enabling the sale of property, and portions of property, on the NAPR website. Improving the liquidity of property assets is expected to boost the economy.

To succeed, this project required good-quality data for the initial input, strong executive commitment and a strong technical partner.

This case demonstrates the use of smart technology to contribute to the areas of smart governance and smart economy. The intervention makes use of blockchain technology to make data about land ownership transparent and to automate changes to this data. The transformation that was needed for this change included changes to the governance structures and legislation, and an automated process that eliminated the need for manual intervention. The blockchain also ensured transparency. This use-case is at a national-level and could be deployed at the local-level.

The outcomes of the intervention include new technology underpinning a system for a land registry that is less prone to fraud. The benefits increased trust in the system and there will be more liquidity in land capital. All this takes place in a context in which there is a historical lack of trust, with high-level support for reforms to the system. There is also an economic driver to make it easier for people to access the value of land for economic benefit.

Lesson learned

- There has to be leadership commitment because there will be resistance to change when trying to address systemic corruption. This is also essential to drive a "trust-free trust" where minimal administration is required for the sustenance of a smart contract-driven blockchain system.[87]
- The project's success depended on strong technology partners. Blockchain is a new technology and, in most cases, has to be built from the ground up on an existing blockchain platform. This calls for deep technology expertise.
- The work done by the NAPR in creating a starting point of high-quality data was pivotal to the success of the blockchain project.

Opportunities	Challenges
• The blockchain enables transparency between the NAPR and the people, thus reducing corruption. • The system enables greater liquidity of hard assets like land, which has economic benefits.	• One of the main challenges is using blockchain for data verification and transparency while not storing too much data on the blockchain and not making personal data public.

Case 8. Transparency in building applications for cell towers

Lack of trust, excessive bureaucracy, and corruption have undermined trust in public administration.[88] As a result, in some countries supervision of public officials has increased to an extent that renders many processes ineffective and personal liability has become a pressing topic for state officials. Consequently, there is a need for new governance and administrative approaches to increase efficiency and new public accountability mechanisms.

Public administration in Italy struggles to offer high-quality services efficiently. This is complicated by complex legacy processes and legislation. In Italy, the level of trust in public administration has declined to the point that, in 2015, 93 per cent of Italians do not trust parliament.[89] Despite the introduction of reforms driven by the New Public Management (NPM) approach, public administration in Italy still follows a bureaucratic model with strongly standardized activities.

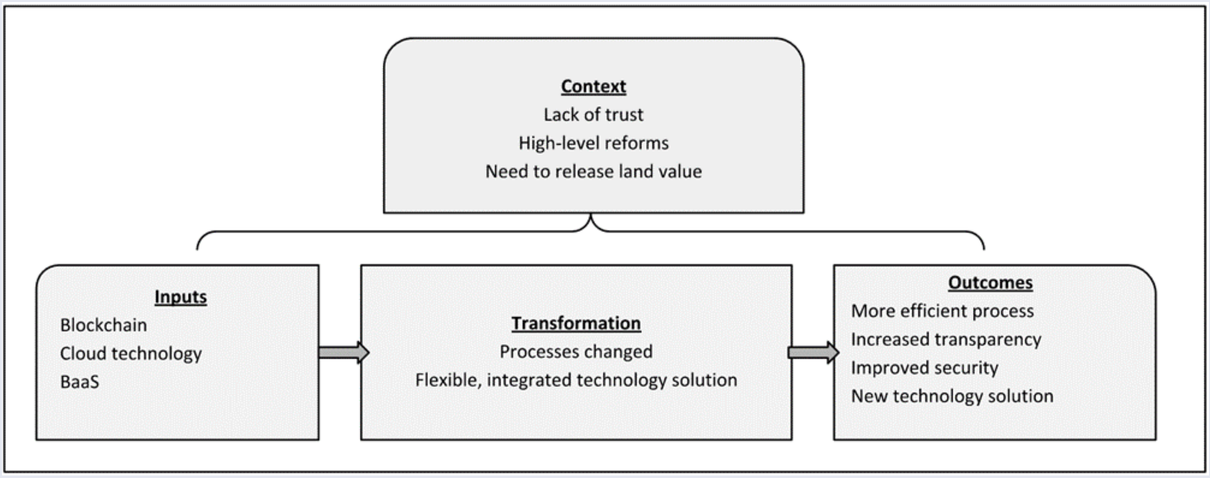
In South Tyrol, the pressure is increasing from the SIAG (Südtiroler Informatik AG), politicians and the public to simplify processes, unify the underlying technologies and improve inter-agency efficiency. Furthermore, due to regulatory changes, demand for end-to-end workflows has increased. This especially pertains to processes in which residents are involved and should be able to check, for example, the state of the request and name of the entity currently working on it. SIAG is a private company jointly owned by the South Tyrolean State Administration, the South Tyrolean Municipalities Association and the Trentino-Alto Adige region, providing e-government solutions.

They initiated the project KIS ("Kommunikation, Infrastruktur, Software") to explore how blockchain can be used to build transparent and efficient government processes.

As an example, they worked on the processes surrounding the building or modifying of cell towers. Roughly 600 applications are submitted each year that concern the building or modification of cell towers. The aim was to model this process, unify the underlying technologies and allow the community to vote on the location of cell towers. The solution had to interface with legacy systems and be cloud-based. There were also problems with digitalization. For example, only a digital document is a valid legal document for the public administration in Italy. Analogue documents, after being digitized and certified, can therefore, be destroyed, however, this process was labour-intensive and complex.

The workflow was complicated and involved three parties: the phone company, the owner of the land where the mast is to be built, and the owners of neighbouring properties. The process includes an environmental impact assessment (performed by the provincial administration) and consultations with the community that is affected by the cell tower. Additional pressure is created by an Italian rule that if the public administration does not respond within 30 days, the construction project is approved. The community and the provincial administration want to keep their authority and hence must ensure fast processing times.

Figure 13: Transparency in building applications for cell towers



The project was approached in three stages. In stage 1, a partnership was established with SAP to develop a proof of concept. A private and permissioned blockchain was established and used to speed up the transfer of analogue documents to digital format, reducing a four-step process to one step and improving security. In stage two, the process to build or modify a cell tower was mapped from end-to-end, starting with the application and ending with the notice of the outcome to the applicant. At the same time, work proceeded on technical matters including putting the system in the cloud and developing a technology stack, using blockchain as a service architecture. Stage three will see the broad rollout of the technology, building on the lessons learned in stages one and two. The intention is to create blockchain-supported processes in various sectors of public governance.

Although this solution is not yet fully implemented, there are lessons to be learned from what has been accomplished so far.

- The project successfully implemented a "back-end-as-a-service" (BaaS) blockchain-based solution in the cloud, and integrated it with a legacy system, proving that flexible solutions can be constructed using blockchain.
- The security of the system was increased, and the process was greatly simplified.
- The critical evaluation of the processes was key to improving the workflow.

Public administration workflows often include numerous internal and external stakeholders who change frequently, as well as a changing legal environment. Blockchain technology can help to decrease uncertainty (for example, through the application of smart contracts) and to establish a single shared truth among the stakeholders. This case demonstrates the use of smart technology to contribute to the areas of smart governance and smart people. As input, the intervention makes use of blockchain and cloud technology, as well as the concept of backend-as-a-service. The transformation that is facilitated includes developing a new, flexible technology solution that can be integrated with existing legacy systems. In addition, the workflow was redesigned and simplified.

The outcomes of the intervention include the new technology solution, as well as benefits in terms of more efficient processes, increased security and improved transparency between stakeholders. All this takes place in a context in which there is a long history of mistrust of public administration and complex compliance requirements. There is also the need to integrate with existing legacy systems and to support the participation of multiple stakeholders in the process.

Opportunities	Challenges
• The backend-as-a-service model incorporating blockchain and cloud technologies could be used to develop further interesting applications in public administration.	• Local legislation affects how processes are needed along with the specific functionality of systems. • Having multiple stakeholders makes it more complex to design appropriate solutions.

Lessons learned and conclusions

- The application of blockchain to provide more efficient and transparent services to citizens turned out to be an interesting testbed that led to numerous learnings for future applications.
- Blockchain technology is still in an early stage and different types of solutions exist. There is a need to experiment with different technical solutions to find those which are most effective.
- Blockchain is useful to create a single point of truth for business processes that span various administrative units and involve different stakeholders.
- Blockchain and cloud computing technologies can be integrated with legacy systems

The study was completed later with four additional ongoing use-cases that offer a diversity of situations for analysis:

Blockchain for cities Use-Cases	
Case 9: Financial Emergency Brake	The *Financial Emergency Brake* case aims to help citizens in debt via an app. The objective is to contribute to the debt reduction by providing citizens with a GDPR-proof way to declare payment inability. This prototype has been developed in collaboration with various partners (triple-helix[d90]) and encompasses the principles of privacy and citizen-centred sharing. Blockchain was one of the technological components chosen because no single partner should have control over all data – a decentralized chain of trust is required. It helps citizens to control their data in a private and secure-way and the system is more stable given that there are multiple databases instead of a single point of failure.
Case 10: Healthy	The use-case *Healthy on the blockchain* is part of the programme fit4Work aimed at making the employee healthier. It is funded by the Interreg North Sea Region. This project is at a very early stage.
Case 11: *Stadjerpass*	The use-case *Stadjerpass* is a voucher system for people with minimum income in Groningen (in the Netherlands). It is an improved version of an existing project that was realized in the '90s. It grants access to social and cultural activities for free or with a discount. It provides access to the swimming pool, or the chance to attend a theatre show with a discount, etc. The municipality adopted blockchain technology for its security and transparency features for handling the transactions.
Case 12 & 13: BLING Projects	For the *Bling* (Blockchain in Government) project, the Howest University of Applied Sciences (Belgium) has been collaborating with the city of Roeselare on 3 blockchain proof of concepts: addressing the accessibility of industrial zones, stimulating local trade and testing a preventive health programme. The purpose is to increase security, data privacy, enhancing accessibility and improve the processes.

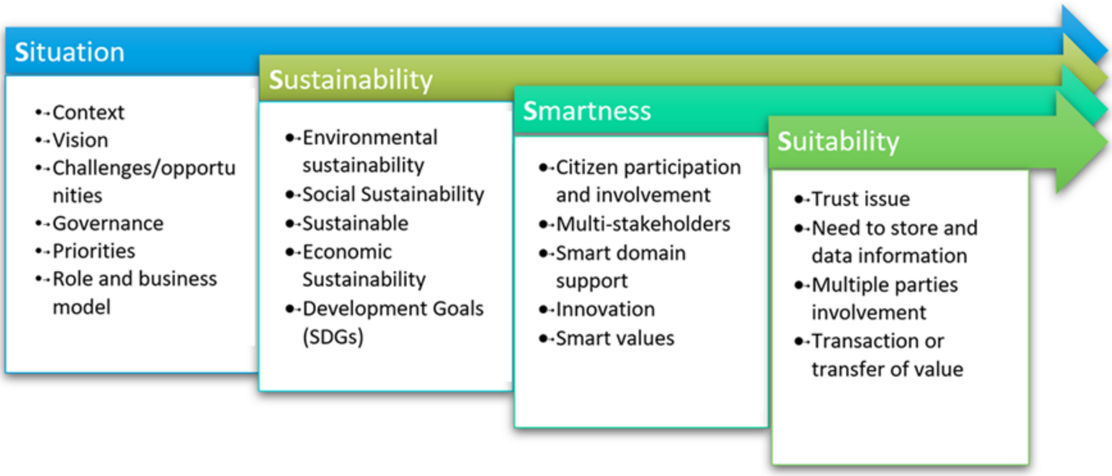
5. Blockchain for smart sustainable cities: cross-case analysis and framework proposal

This section presents a cross-case analysis highlighting the challenges, opportunities and lessons learned from the use-cases presented previously. The purpose of the analysis is to understand the complexity of the projects, and to identify the critical elements and patterns for the application of blockchain in smart cities context. The findings from these analyzes are summarized in the "**4S framework**" below (Figure 14).

This "**4S Framework**" encompasses Situation, Sustainability, Smartness and Suitability. The four dimensions of the framework are linked and interdependent, which means that the context and the challenges of the city will define the sustainability issue to address the priority and translate it into smart city initiatives, supported by the right type of blockchain technology. Vice-versa, the suitability of blockchain is not important if it does not support the city to become smarter. There is no smartness without sustainability, and sustainability might not have the right impact on the specific context of the city.

For the purpose of this report, blockchain for cities (B4C) use-cases have been analyzed based on these axes using evidence-based models and dimensions from the academic literature. The findings of this analysis are summarized in Table 8 and explained in detail in the remaining sections of this report.[e]

Figure 14: 4S Framework of blockchain for cities



Blockchain in this framework is considered as a digital innovation that requires strategic and operational planning to build a smart and sustainable city. A different framework to define the "**4S**" dimensions of blockchain for Smart Sustainable Cities framework was used. This framework will be explained later in detail.

The "Situation" detailing will be presented with the general context of the blockchain-based city project.

[d] Success of a city's transition to a smart city depends on the synergic action by the triple helix key actors: public bodies, universities, and private companies (IEEE, 2016).

[e] The green ticks denote the characteristics that are inherent to the use-case and the red crosses indicate characteristics that are absent.

Table 8.A: Comparative analysis of the blockchain for cities use-cases

Perspective	Characteristics	Weekfairs	Active Citizen	Land titling	Energy Systems	Debt Relief	e-vote for cell tower
Suitability of Blockchain Technology	The entities and users of the system do not trust each other.	✗	✓	✗	✓	✓	✗
	It is not important to have a trusted third party (TTP)	✓	✓	✓	✗	✗	✗
	The users of the system are not known.	✗	✓	✗	✗	✗	✗
	The control of the system by a specific entity is not required.	✗	✓	✓	✗	✗	✗
	It is necessary to remove intermediaries.	✗	✗	✓	✓	✓	✓
	It is necessary to work with digital assets.	✓	✗	✓	✓	✓	✓
	It is necessary to maintain a permanent record.	✓	✓	✓	✓	✓	✓
	It is necessary to implement a contractual relationship.	✗	✗	✓	✓	✗	✓
	It is necessary to store transactions states	✓	✓	✓	✓	✓	✓
	It is not necessary to store sensitive data.	✓	✓	✓	✓	✓	✓
	It is not important to be able to delete records	✗	✗	✗	✗	✗	✗
	The use case requires shared write access.	✓	✓	✗	✓	✗	✓
	High performance to validate transactions is not important.	✗	✓	✗	✓	✗	✓
	It is not necessary to store a large volume of non-transactional data.	✗	✗	✗	✗	✓	✓
Contribution to smartness	The initiative changes relationships between the stakeholders or its roles.	✗	✗	✓	✓	✓	✓
	The initiative impacts smart domains.	✗	✗	✓	✓	✓	✓
	The initiative is innovative.	✓	✓	✓	✓	✓	✓
	The initiative supports smart city values.	✓	✓	✓	✓	✓	✓
Contribution to sustainability	The initiative contributes to economic sustainability.	✓	✗	✓	✓	✓	✗
	The initiative contributes to environmental sustainability.	✗	✗	✓	✓	✗	✗
	The initiative contributes to social and institutional sustainability.	✓	✓	✓	✓	✓	✓
	The initiative supports the Sustainable Development Goals.	✓	✓	✓	✓	✓	✓

Table 8.B: Comparative analysis of the blockchain for cities use-cases (end)

Perspective	Characteristics	Digital Democracy	Claim Verification 18+	Financial Emergency	Healthy	Stadjerpas	Bling1	Bling2
Suitability of Blockchain Technology	The entities and users of the system do not trust each other.	✓	Not available	✗	✗	✓	✓	✓
	It is not important to have a trusted third party (TTP)			✓	✓	✓	✓	✓
	The users of the system are not known.	✓	✓	✗	✓	✗	✓	✗
	The control of the system by a specific entity is not required.	✓	✗	✓	✓	✗	✓	✗
	It is necessary to remove intermediaries.	Not available	Not available	✗	✓	✗	✓	✓
	It is necessary to work with digital assets.	Not available	✓	✗	✓	✗	✓	✓
	It is necessary to maintain a permanent record.	✓	Not available	✗	✗	✗	✓	✓
	It is necessary to implement a contractual relationship.	✗	✗	✗	✗	✗	✓	✓
	It is necessary to store transactions states	✓	✓	✓	✓	✓	✓	✓
	It is not necessary to store sensitive data.	✗	✗	✓	✗	✓	✗	✗
	It is not important to be able to delete records	✗	✗	✓	✓	✗	✗	✓
	The use case requires shared write access.	✓	Not available	✗	✗	✗	✓	✓
	High performance to validate transactions is not important.	Not available	Not available	✓	✓	✗	✗	✓
	It is not necessary to store a large volume of non-transactional data.	✓	Not available	✓	✗	✓	✓	✓
Contribution to smartness	The initiative changes relationships between the stakeholders or its roles.	✓	✓	✓	✓	✗	✗	✓
	The initiative impacts smart domains.	✓	✓	✓	✓	✓	✓	✓
	The initiative is innovative.	✓	✓	✓	✓	✓	✓	✓
	The initiative supports smart city values.	✓	✓	✓	✗	✓	✓	✓
Contribution to sustainability	The initiative contributes to the economic sustainability.	✗	✗	✓	✗	✓	✓	✓
	The initiative contributes to the environmental sustainability.	✗	✗	✗	✗	✗	✓	✓
	The initiative contributes to the social and institutional sustainability.	✓	✓	✓	✓	✓	✓	✓
	The initiative supports the Sustainable Development Goals.	✓	✓	✓	✓	✓	✓	✓

5.1 The situation of blockchain for cities

The cases described in this report underscore cities initiatives from different countries: Russia, The Netherlands, Italy, Georgia and Spain. The case of land registry from Georgia is a central government use-case; however, it does provide interesting learning outcomes for blockchain initiatives for local public service and government.

Table 1 (Appendix 2) provides an overview of the general context of B4C use-cases describing the status of the project, city or community, the level of governance, the stakeholders involved in the initiative, transparency, privacy and the governance model.

(1) Status of the project

Most of the use-cases studied confirm that blockchain applications are emergent or at an early stage of development in the smart city context as just 20 per cent have an implemented solution. These findings are consistent throughout the practice in the public sector. The major part of the proof of concept (POCs) is in its initial stages, and few pilot projects and prototypes have demonstrated blockchain feasibility or practical applications. The majority of adopters have mainly been experimenting with blockchain in an attempt to understand better, rather than to monetize the technology.[91] Practitioners and experts consider that the public services are proposing advanced use-cases of blockchain. However, it is important to shed light on the type of transformation that is planned in the project.

(2) Government level

Among the blockchain technology applications for government and public institutions, 39 per cent started at the federal level, and 23 per cent at the national government level, and all the other cases are developed locally. The data showed that for most of the cases, even though they are deployed at the local level, the funding and investment and the innovation came dominantly from the regional, federal or national-level. Minimal number of initiatives were kick-started completely by the local stakeholders.

(3) The main stakeholders

Seventy per cent of the cases involve the creation of public and private partnerships (PPP) and consortia with private companies, research institutes and universities. Implementing PPPs and cooperation between blockchain actors and envisioning a new role for government as part of consortia are critical drivers of the blockchain development. It is a significant paradigm shift. However, this type of model requires collaborative governance mechanisms that are challenging for the public sector.

(4) The transparency importance

Seventy per cent of the cases declared transparency as the most important motivation for blockchain adoption. Stakeholders have high expectations of transparency and accountability from public services. There is a growing demand from citizens for openness and to reduce corruption. It is particularly predominant where there are inequalities, risks of corruption and fraud.

(5) Privacy importance

The importance of privacy is different from one case to another. It also relates to distinct factors such as the application area of the case, the type of data stored, the different levels of understanding about the risks and implications when there is a lack of privacy, the different levels of technical knowledge about privacy-by-design in the context of blockchain, and the available expertise to implement them. It depends also on the applied laws and regulations. Governments willing to use the technology for smart cities need to consider that an in-depth analysis of each project is necessary. The need for privacy can vary from none (i.e. blockchain for transparency of the public expenses) to indispensable (i.e. blockchain use-case for the healthcare system). A deeper analysis of this dimension is critical as privacy is a right (United Nations, 1948). The level of complexity to implement privacy could vary considerably depending on the type of blockchain and the purpose of use.33 The most sensitive cases around this topic are the Debt Relief, Digital Democracy and Claim Verification 18+. There are privacy challenges that may hinder the applications of blockchain, and privacy threats depend on specific cryptographic defence mechanisms.[92] It is not right to say that blockchain supports or not the privacy and data protection of the users. It depends on how the technology is used in each case and on the type of blockchain implemented.[93]

(6) The definition of the governance model

A governance model was defined in 30 per cent of the cases. The lack of governance model is one of the main barriers to blockchain adoption in the governmental context. The governance model is especially crucial in the context of smart cities as it generally involves multiple stakeholders, not only during the project phase (such as in the case of Digital Democracy and Debt Relief) but also during and after the implementation. The definition of the governance model[f] may facilitate the alignment of expectations, the anticipation of possible conflicts of interest and the definition of the main guidelines around the solution in all the stages of development. Thus, each stakeholder must understand its role in the life cycle of the solution. The governance model might lead to the transformation of the governmental body involved to benefit from the distributed nature of the blockchain. It might create adverse reactions that need to be managed.[94] In all the studied cases, the governance model was essential, and its complexity increased with the number of entities involved. The parties involved in a solution can vary a lot. The more partners are involved, the higher the level of complexity, and the more critical the governance model becomes.

[f] It is possible to define two different types of governance models: governance by blockchain and governance of the blockchain. The first is related to the use of the technology to implement governmental processes, organizing information exchange and transactions between users. In this way, the technology is used as a mechanism to implement the governance related to a process. The second type is related to how the life cycle of one specific solution will be guided, the roles, responsibilities and alignment of expectations between the stakeholders involved (Olnes et al., 2017).

The Situation dimension is particularly essential, and it makes the distinction from one case to another. It refers to the general context, but it also highlights the vision, the challenges and the opportunities that the cities are facing. For smart city initiatives, there is no one-size-fits all solution and it depends on the context (as explained by the UNU-EGOV smart city model in Figure 5). This report also examined the study on blockchain use-cases of land registry (Georgia, UK and Sweden). From a technical point of view, the three projects were successful; however, the outcome, the progression and the application are very different due to the situation. Contextual perspective, vision, regulation, governance and the role attributed to the blockchain technology in the project are the main aspects that influenced the outcome of the blockchain-based project.

Keeping the above in mind, it is critical to define the vision, the aimed transformation of the city and the objectives, as well as the elements to consider when addressing the priority challenges. It will contribute to better management of the complexity of the blockchain-based smart, sustainable city initiatives. The existing classification that defines the use-cases according to the role of blockchain as a transformer or an enabler – depending on how it is applied from one context to another – can be used. It could be relevant to put into perspective the initiative depending on the role played by the blockchain. The solution requires adaptation to the contextual specificities on smart, sustainable cities. Each city has its culture, challenges, needs and priorities that will define the role of the blockchain solution and the value to create. It will significantly anchor the decisions and choices in terms of applicability and suitability, smartness and sustainability of blockchain and help to better define the needs and requirements.

5.2 Sustainable development in the B4C initiative

The second critical dimension to consider while deciding on adopting B4C is sustainable development. Several studies are presenting blockchain as a technology that could play a significant role in the sustainable development, the global economy as well as improving people's quality of life and contribute positively to the 2030 Agenda for Sustainable Development.[95] Furthermore, the World Economic Forum is estimating that 10 per cent of the Global GDP will be stored on blockchain technology in less than a decade.[98] For this analysis, this report has established four dimensions to measure sustainability (see Table 9).

Table 9: The sustainability in blockchain for cities

Sustainability of B4C	1. The B4C initiative contributes to economic sustainability.
	2. The B4C initiative contributes to environmental sustainability.
	3. The B4C initiative contributes to the social and institutional sustainability.
	4. The B4C initiative supports the Sustainable development Goals (SDGs).

The economic, social and environmental aspects of sustainability are the foundational aspects of the sustainable development introduced by the United Nations. These three domains of sustainability are represented unevenly through use-cases of blockchain for cities. It indicates that thus far, the results are mixed (see Table 2 Appendix 2). The B4C contributes more consistently to economic and social sustainability than to the environmental one. Some of the SDGs are supported on certain aspects; however, they may impact others negatively based on various factors.

(1) Economic sustainability

Economic sustainability is measured by the contribution of the initiative to the household income and expenses, employment and businesses. Sixty-six per cent of the B4C use-cases envision contributing to economic sustainability, mainly to improve the household income and expenses. Blockchain worldwide contributes to building a smart economy, smart transportation and mobility.

It also aims to improve effectiveness, and process transformation, as well as improve efficiency. The concept of economic sustainability is becoming increasingly important and is carrying more weight at the city level. Smart cities as mentioned previously have a considerable potential to improve sustainability, but it is currently limited by "market-focused" economic models. The global smart city revenue is estimated to grow to USD 88.7 billion by 2025.[g] Cities are looking into technologies such as blockchain to create efficiencies, improve and create economic development and are exploring different business models to acquire more autonomy from the central government. According to the United Nations University/DACA[99] study on sustainable development, there is a clear limitation on how much efficiency can be gained by a city as an existing urban system, as well as on the economic value created, and on the longer-term sustainability obtained by optimizing the system in isolation. The same study highlights that cities worldwide are becoming passive customers for technology companies, and this could lead to serious long-term sustainability issues. To prevent these trends and patterns, local government should play a central role in building ecosystems and creating partnerships to enable ICT development, regulations, support and implementation, which are critical for long-term sustainability.

(2) Environmental sustainability

There is no supporting evidence of blockchain capabilities to address environmental issues; however, there are currently more than 65 initiatives that are at an early conceptual or pilot stage.[100] Some of the initiatives are in middle-income countries such as Ghana, Brazil or Georgia. Blockchain could be a promising technology for harnessing the environmental sustainability based on its ability to provide a transparent and verifiable record of the transactions, and to trace these records. Three uses-cases are addressing environmental sustainability (Land registry, Energy system and *Bling projects*). Blockchain could play a role and have a significant contribution to environmental sustainability with respect to three main aspects: resource rights, product origins and as an incentive system:

(1) The cases of the land registry in Georgia (private property rights to land) or the energy system in South Holland (rights to use resources and prevent overuse) are cases related to resources rights. In both cases, the focus is primarily on the economic aspect rather than the environmental benefits. These use-cases could provide important benefits to low- or middle-income countries where the resource rights systems are either absent, informal or show a great deal of corruption.

(2) Blockchain could also constitute a relevant opportunity to encode verifiable information about product origins. The technology is providing, in this case, relevant information to consumers about the environmental impact of their purchasing behaviour, which could contribute positively to the SDG12 "responsible consumption and production", where the results have not been promising.

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[g] Smart cities and sustainability, Evidence brief economic and social Research council, April 2018 https://esrc.ukri.org/files/news-events-and-publications/evidence-briefings/smart-cities-and-sustainability/

(3) Blockchain could support applications for incentive systems for environmentally sustainable behaviours. Among the use-cases collected and analyzed,[h] one consisted of a blockchain-based reward system developed in Mauritius to promote sustainability and incentivize citizens to contribute to the environment sustainability among other actions.

The main issue is related to the contradiction faced between blockchain technology and environmental sustainability. It is often qualified as a non-sustainable technology. As explained in the first section, blockchain technology in itself has an environmental footprint, especially in using the proof-of-work consensus to validate the transactions. It is also important to highlight that effort and research are conducted, notably, through the development of an alternative protocol to create new ways to reduce the energy intensity, which will increase the opportunities of this technology to contribute to sustainable development.

(3) Social and institutional sustainability

The social aspects of sustainability are focusing on well-being, social care, education, health and safety use-cases. The social sustainability is also defined in the B4C use-cases by involving the human and social value that can be driven through the smart people, the governance and the community initiatives. It is measured by the contribution to the demographics, housing, education, security, health, well-being, social and community services, expenses and public administration domains. All the B4C uses-cases showed contributions to one or more dimensions of social or institutional sustainability (Table 2). From one side, studies demonstrated that smart cities are failing at creating more inclusive, sustainable and democratic cities as the emphasis is on the economic value and the technological aspects. From another perspective, blockchain constitutes a relevant means to develop more sustainability at the social level, as its features could reinforce the social and institutional level with more inclusion, empowerment, transparency, accountability enhancing, bureaucracy reduction and power asymmetry.[101] However, poorly planned blockchain-based smart city initiatives can cause more societal harm than they contribute to sustainability. The negative outcomes of poorly planned blockchain activities include the technological exclusion of people due to lack of accessibility to technology, low digital literacy, misuse of sensitive and personal data, vulnerability and violation of privacy rights, economic and the market interest being prioritized over social issues. Smart city initiatives and projects are providing increasingly data collection and access to private and large technology companies without thoroughly assessing the implications for the governmental institutions, the residents and citizens. Blockchain should be leveraged for smart city initiatives that foster residents' and citizens' participation, involvement and empowerment in the governance, regulation, data control and city planning to contribute positively to the social, as well as institutional sustainability.

[h] The use-case was not elaborated on in this report as it is classified as blockchain application initiated by civil society and not a blockchain for cities use-case implemented by public entity.

(4) Sustainable Development Goals (SDGs)

Sustainability could be assessed through the compliance and contribution of the B4C projects to the SDGs. The adoption of the 2030 Agenda for Sustainable Development (September 2015) by the United Nations General Assembly aims to provide clear objectives to monitor the sustainable development goals and inclusive growth. The SDG11 "*make cities inclusive, safe, resilient, and sustainable*" is globally addressing the main purpose of the B4C, but not exclusively. The use of blockchain for cities, if it is adopted primarily for sustainability considerations, could also consolidate the support of smart, sustainable cities to *reduce poverty* (SDG1), contribute to the effort towards *good health and well-being* (SDG3), *decent work and economic growth* (SDG8), *peace, justice and strong institutions* (SDG16) and the *partnership for the goals* (SDG17).[102] The B4C use-cases confirmed the contribution of blockchain to these five SDGs. Blockchain technology could also support improvement in terms of SDG12 through the product tracing origins application, which is a critical solution for responsible consumption. However, it is essential to highlight that the use of blockchain for smart cities will not reduce inequalities (SDG10). It will be most likely to work against energy consumption (SDG7). It is not clear whether the use of blockchain will contribute positively to SDG9 relating to *industry, innovation and infrastructure*. Even though the majority of the B4C use-cases consider that their blockchain solution will contribute to SDG11, the research and data analyzed for the SDG11 show that only a limited number of IT-based smart cities initiatives are adding value, and important challenges persist worldwide.

Figure 15: Blockchain for cities support to the SDGs

The Sustainability dimension refers to the economic, environment and sustainable dimensions in synergy. The SDGs are a broad and universal agenda. It will not be challenging to contribute to the SDGs and improve a city's overall sustainability. What will make the difference is that each city assesses its challenges and sets its priorities and targets in terms of sustainability to determine the right means and explore if blockchain could be an option to explore for the target goals based on the findings presented in this deliverable.

Blockchain remains an essential tool. The most important objective would be to leverage the political will, the correct policies and to build an adequate partnership for achieving a more inclusive and sustainable city. Sustainability should be one of the top priorities in deciding to adopt the B4C initiatives, as increasingly policies and actions are engaged in endorsing inclusive growth, reducing inequalities and facing the challenges posed by environmental issues. It should not be addressed only at the national level as they require the involvement of the cities as well.

5.3 Smartness of a blockchain-based initiative

The main question addressed by the smartness dimension is whether or not a blockchain initiative will contribute to making the city smarter. There is a wide debate on the characteristics of a smart city, and how to determine which cities are smart and which are not.

"Smartness" depends on the vision of a city performing well in a number of areas, and the effective harnessing of the city's endowments through the activities of competent and aware stakeholders including officials, private companies, social entrepreneurs and individual residents. It is a continuum along which cities and communities find themselves positioned due to their history, geography, resources and initiatives. The task of cities is not to reach some ideal state in which they will earn the title "smart", but rather to improve; to move along the continuum to a state of increasing smartness from wherever they start. Taking this approach means that smart initiatives can be applied in large and small communities, regardless of their levels of development. Therefore, the 4S Framework considers the characteristics of smart initiatives that will benefit cities and communities such as the core values that drive the initiative, the smart domains and the areas that will be impacted by innovation (Table 10). The B4C use-cases smartness dimensions are summarized in Table 3 (Appendix 2).

Table 10: The smartness of blockchain for cities

Smartness of B4C	1. The B4C initiative changes the relationship between the stakeholders and their role.
	2. The B4C initiative impact smart domains.
	3. The B4C initiative is innovative.
	4. The B4C initiative supports smart city values.

(1) Changes in the stakeholders' relationship and their role

The city becomes smarter when it experiences changes in the relationship between the stakeholders in different ways. Making a city smarter is built by collaboration among a collective of stakeholders that have different roles and capabilities, in order for the effort to be successful. Blockchain technology, by definition, changes the relationship between the stakeholders. However, in 30 per cent of the cases there were no significant changes in the relationship between stakeholders. All the rest of the cases identified different types of change such as the inclusion of new stakeholders (i.e. Georgia Land registry), or moving from a passive role to a more active role (i.e. e-vote for cell towers). Changes in nature and the frequencies of interactions were observed (i.e. in the case of financial emergency or the health cases, among others). The empowerment of the citizens or the residents of the city constitutes a drastic change in the power dynamic allowed by the blockchain technology properties. For a smarter city, citizens need to be fully involved and gain from the use of innovative and disruptive technologies (Table 4, Appendix 2). Blockchain is enabling the citizens by providing them with access to the data (role of reader)[i] and allowing them to write in the system (role of a writer)[j] and to keep the records of the data.

For 50 per cent use-cases, allowing the citizens to read the data is very important to ensure transparency and good governance such as citizen participation and collaborative decision making. Only 75 per cent of the use-cases provide the need to have authorization (under defined circumstances). Citizens as end-users should be the primary target and should benefit from more efficient transactions (e.g. fast and inexpensive payments), increased transparency, verifiability and accuracy of the information, and ability to control their data and identity from the public services. Blockchain will, in this sense, contribute to improve and/or transform the relationship and interaction between the citizens and the public services, in order to reduce power abuse and corruption.

(2) The blockchain for cities impacts the smart domains

Six domains that provide tools to achieve integrated and open governance, promote cooperation and co-decision making, while incorporating the active participation of citizens: (1) smart economy, (2) smart mobility, (3) smart environment, (4) smart people, (5) smart living and (6) smart governance. The UNU-EGOV framework on smart city (Figure 5) maps the domains within the process of becoming smarter in terms of the context, inputs, transformations and outcomes.[k] Historically, the evolution of the smart city concept is driven mainly by technological progress, which explains the failure of the project. The main issue with blockchain projects is also the hype and the overemphasis on the technological aspects. Most of the use-cases presented in the report are contributing to one or more of the smart domains identified. However, some of the cases are more motivated by technological innovation than by providing a solution to a specific domain. In this case, the solutions are associated to more than one domain, which explains the unclear definition of the smart domain process and the outcomes in some cases very generic and not clear. Moreover, some of the blockchain-based initiatives and pilot implementation projects will struggle to achieve a significant uptake and retention of the technology due to the inability to engage and actively involve the users, especially the citizens.

(3) *The blockchain for cities is innovative*

The innovative aspect defines the smartness of a solution. It elaborates on how to use IT to either transform existing processes, better serve the citizens (such as an example of smart administrative model), offering new and innovative services to the citizens and residents and new service delivery, providing new ways of regulation and innovating the partnership. The two types of innovation are explicitly associated with "smart governance". Several innovative behaviours characterize smart governance, such as the empowerment of the residents to the role of regulators in the city or the partnership, which is defined by the willingness of cities to propose collaborative urban governance also called "the smart urban collaborative model" of governance.[103] Innovativeness is intrinsic to the B4C use-cases as blockchain is disruptive. All the use-cases consider that their smart city initiative using blockchain technology is innovative in at least one of the aspects. However, the innovativeness needs to be considered in direct relation to the specific context.

For example, the use-case of land registry in Georgia is innovative in all the aspects as it did not exist previously in the country. However, for the same project of land registry in Sweden, the innovative aspect aims to improve the existing land registry process. The project remained at the experimentation level and "it was never integrated into the production system of the land registry" as the existing land registry system is effective and the innovative process was not enough to justify the need to migrate to the blockchain system.

(4) *The blockchain for cities supports smart city values*

Smart city values are described by the provision of better infrastructure and service, the improvement in job creation and economic growth, the entrenchment of civic values, supporting social inclusion, equity and fairness, protecting the environment and sustainability and improving city governance and engaging the citizens in governance. There are two dominant shared values. The first one is to provide the citizens and the city with better infrastructure and service. Several public services are moving towards blockchain-based systems mainly motivated by the security factor. The use of smart contract or decentralized autonomous systems based on blockchain technology is often presented as more secure, reducing uncertainty manipulation, corruption and human errors. It is adopted unanimously by all the cases (see Table 5). The second shared value is the entrenchment of civic values, supporting social inclusion, and equality. Indeed, the use of blockchain supports these values by reducing the risk of falsification, improving transparency and ensuring privacy and anonymity, among other things. The use-cases often rely on the public key-based identity to provide pseudo-anonymity protection, such as identities for e-voting (i.e. active citizen and e-voting) and tax payers (i.e. debt relief case or financial emergency) the event-ticket holder (i.e. Stadjerpass case), patients or employees (i.e. Healthy). They also rely on encryption such as zero proof system to ensure privacy allowing only to the right party to open and read the content even though the information is diffused and received by multiple parties.

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[i] The readers of the data are the participants who can access the records in the system.

[j] The writers are the users who can submit a record or a transaction in the blockchain.

[k] The inputs represent technologies and tools that can be used to address the problems. The context is related to the specific situation and core values and drivers of the city or community. The transformation considers the decisions regarding approaches, governance, and the outcomes are the benefits and innovations resulted from the transformation.

The Smartness dimension links the smartness to several aspects, with the support of the technologies. Studies on how the emerging technologies are contributing to making cities smarter show a positive impact – mostly in high-income countries –in facilitating economic development, increasing public efficiency, facilitating good governance, enhancing cooperation, empowering citizens and improving quality of life. However, it also showed negative impacts such as aggravating or hiding existing urban problems, polarization and increased inequality.[104] Thus far, the positive effect on social development, social capital citizen involvement, innovation, protection of the environment and sustainable development is not proven.[105] It is critical to understand the specific role of the blockchain technology in the smart city to assess its contribution to smartness and sustainability.

5.4 Suitability of blockchain technology in smart city initiative

The suitability of blockchain technology is studied through the analysis of the technical characteristics of the blockchain for cities, as well as the analysis of the decision models and trees of the applicability of blockchain in the context of smart cities initiatives.

5.4.1 The technical characteristics and properties of blockchain for cities

The technical characteristics refer to the properties of the blockchain technologies, the consideration during implementation and the technical deployment of technology. This report compares the cases for the integration with the legacy systems and other systems, the importance of the security, the type of framework used, the current users of the system, the type of blockchain, the type of use of the blockchain, as well as the type of cryptography used (Table 5, Appendix 2).

(1) Integration with Legacy systems

The integration of the cases with legacy systems and the interoperability is considered as critical in 70 per cent of the cases, which show the importance of this dimension. In the case of *Stadjerpass*, the integration with the existing legacy was the main challenge due to the need to build a separate application to transfer data between the blockchain and the data of the administration. A lack of interoperability between blockchain frameworks, networks and platforms, as well as between blockchain networks and legacy systems, is a major concern. Nearly 70 per cent of the distributed ledger technologies claim to be interoperable with others.[106] However, it is mostly limited to the public Ethereum network, and, to a lesser extent, Bitcoin. When a blockchain solution needs to be inserted into an existing IT infrastructure, and receive inputs from upstream systems, it is important to consider policies and procedures over legacy applications and processes. In order to maximize the power of blockchain and distributed ledgers technology agreements will need to be reached about data interoperability, policy interoperability and the effective implementation of international standards.

(2) Agility of the system

The agility of the system and the need to integrate the blockchain applications with other systems in the future seems to be less important. Only 23 per cent of the use-cases emphasized its importance. It is unlikely that complete historical data from legacy systems will be taken and entered into the blockchain, particularly if it is a significant amount of data. Particularly, considering that any data are tamper-proofed once in a blockchain, and that data are still vulnerable to common IT risks while outside the blockchain. The transition of data between different systems needs to happen in the most controlled manner, given the unique IT environment of each case. Experts and researchers in the blockchain system are already looking into this issue and proposing solutions such as Cosmos, an ecosystem of blockchain applications that can scale and interoperate with each other using a new consensus mechanism considered as Blockchain 3.0, after Bitcoin and Ethereum.[107]

(3) Blockchain solutions

Security is extremely important for all the use-cases. It constitutes one of the main concerns impacting the legitimacy of the use of blockchain technology tremendously. In this context, most of the interviewees presented blockchain as a secure option. Blockchain is often adopted because of its security properties, particularly in the case of public blockchain. However, 70 per cent of the cases opt for a private distributed ledger and permissioned blockchain mainly based on Ethereum and Hyperledger (e.g. Hyperledger Fabric and private forks of Ethereum), where only authorized parties can access the data. Moreover, the consensus mechanism differs from one case to another (proof of authority, proof of stake, proof of concept) but the majority (70%) of the cases have not yet reached this stage.

(4) Scalability

Scalability refers to the ability of the system to sustain performance while growing and expanding, such as increasing the number of users, storage requirements, and the response time per transaction as the network grows. The number of users varies greatly from one use-case to another depending on the progression in the development, and the targeted number of users as well. In some cases, such as Digital Democracy, there are 60 000 users; while in other cases there are only 33 users. The scalability constitutes one of the main challenging components regarding blockchain adoption. However, it is also considered as a temporary technical issue that might be resolved by further research and development, as new protocols evolve.

(5) Blockchain applications

In blockchain technology, the smart contract is the most adopted in the smart city context (85% of the cases). It allows derivatives to be executed automatically, and enables a variety of transactions without the need for centralization, particularly in the case of voting systems for tamper-proof ballots and election results (Active citizen in Moscow or the e-vote system for cell-towers in South Tyrol). However, the use of Cryptocurrencies applications seems not to be critical in the smart city context. None of the use-cases is planning to use cryptocurrencies in their blockchain project. Even though across the sector, most of the blockchain applications entail the use of cryptocurrencies. The use of token applications is also highlighted as an essential element for blockchain adoption, despite the fact that only one case confirmed the use of a token (e.g. Energy system). Studies showed benefits from introducing cryptocurrencies and tokens on blockchain platforms as technology or productivity progress, such as the tokenization of the e-participation. It is also shown to increase the user adoption and empowerment.

(6) Type of cryptography

The most frequently used cryptography in blockchain for cities is the public key cryptography and hash function. There is also an increasing use of the zero-knowledge proof, which is a new technology developed to allow institutions to transact on the public blockchain while still protective of citizens' sensitive and private data. However, it is a concern as it remains unclear if citizens understand what they agree on, the level of information they want to disclose, to whom they want to disclose their data and their legal rights in case of data misuse or data breaches.

5.4.2 Blockchain application in the smart city context

The decision between traditional databases or blockchain is not simple. The most appropriate solution depends directly on the application scenario[16]. There are several models, decision trees and frameworks that were developed to support the decisions on the applicability of blockchain technology.[108]These models vary according to the business needs, to the requirements of the system, to the industry and other dimensions and level of details are provided.

Some elements seem to be recurrent, and most of these models agree on determining the type of blockchain based on whether the organization should adopt public/private or permissioned, permissionless should be selected.

After studying more than 20 decision models, this report selected and analyzed 14 dimensions that are supported with evidence from academic studies to define the factors that are critical to consider for the suitability and applicability of blockchain in the context of smart, sustainable cities. The purpose of this report is not to propose a new decision model for applying blockchain, as there are already several relevant decision models proposed in the literature. Moreover, the UN recently published a Practical Guide on Blockchain Technology in the UN system.[112] The main purpose is better to understand these main factors for informed decision making. These variables are summarized in Table 11.

Table 11: Suitability dimensions of blockchain for cities

5.4.2.1. Suitability of B4C	1. Trust between the users and the entities
	2. Third party as a requirement of the system
	3. The users of the system are known
	4. The need of control of the system by a specific entity
	5. Removing the intermediaries
	6. Digital assets
	7. Permanent record of information
	8. Contractual relationship
	9. Transaction state record
	10. Sensitive data
	11. Storing volume of non-transactional data
	12. Deleting data
	13. Writing access
	14. High performance for transaction validation

(1) Trust and similar interest between the users and the entities

In general, if there is trust, most of the decision models recommend not considering blockchain as a top priority application to adopt.[113] If the writers all mutually trust each other, i.e. they assume that no participant is malicious, a database with shared writing access could be considered a better solution. There is trust among the users in fewer than 50 per cent of the use-cases. The majority of these use-cases have adopted a private blockchain. Under these conditions, the choice of blockchain might be suitable if the option of using blockchain is not associated with the need for a trust-free application. This might create an inconsistency between the rule applied and the actual case. However, the decision could be problematic and inconsistent with a public blockchain type. This dimension is not a priority in defining the suitability of blockchain. However, it is critical to determine the type of blockchain to implement.[114]

(2) Presence of a third party in the system (TTP)

Blockchain added-value is based on the principle of decentralization. There is no central authority of control during the transactions. The use of blockchain is not relevant and not suitable if a TTP is needed. However, 30 per cent of the cases consider its presence necessary. Blockchain is removing the traditional trusted third-party, however, new third parties are created with new roles. It is critical to understand that it is a paradigm shift, a different type of system that required various tools for analysis. The parties in the blockchain need to trust each other otherwise the potential for using blockchain is limited to the use-cases, which makes it possible to use blockchain and have a third party (i.e. Energy system and Debt relief use-cases). Consequently, this dimension is not critical for the applicability of blockchain for the city, however it will define the type of blockchain which is eventually chosen.

(3) The users know each other

If the users know each other, most likely blockchain is not necessary.[115] However, this can be a case for a permissionless blockchain, depending on the other requirements. If the users are known but not trusted, a permissioned Blockchain is recommended. If the set of writers is not fixed and known to the participants, a permissionless blockchain is a suitable solution.[116] In public service, the writers are known as government agencies.[117] If they are considered to be trusted, the rule states that blockchain technology is not the most suitable. However, if they are not all considered as trusted, it is recommended to use a permissioned blockchain. The use-cases in this situation use Bitcoin blockchain, which is a permissionless blockchain (see Table 2). This is also possible because of the off-chain mechanism that can be used to recognize records written by the authorized parties. In this specific situation, the case is using the government agencies publicly-released blockchain identity. This condition does not systematically question the applicability of blockchain; however, it helps to determine the most appropriate architecture for the blockchain system (See Figure 3).

(4) Need for control by a specific entity

Blockchain is a shared ledger, and if a specific entity is needed for the control, a normal database could be more suitable than blockchain.[118] This is consistent with most of the decision models analyzed. However, 60 per cent of the use-cases are assuming the need for the control of a specific entity. Two fundamental conditions must be met without having to rely on any particular party in the system. Often participants need to trust each other despite using a distributed ledger. Otherwise, the use of blockchain to replace the control of one specific entity or TTP as presented earlier is limited. It is most likely that other more efficient or more practical solutions exist. This dimension is similar to the presence of a third party. The need for control will not specifically question the applicability of blockchain but will determine the type of blockchain to adopt for the city.

(5) Removing the intermediaries

Blockchain is recommended when a business process can be redefined to remove intermediaries.[33] It is one of the main criteria of blockchain applicability.[119] Nearly 40 per cent of the cases did not require the removal of intermediaries, given that they are dealing directly with the citizens, which demonstrates that this rule is not adequate in the context of public service whether it is at the local level or national level.

These use-cases prioritize the immutable record capability as the main value proposition of blockchain to motivate the use of blockchain, and not necessarily the disintermediation property of blockchain. A McKinsey report (2018) also specified that the role of blockchain should not be limited to a disintermediator. In brief, removing the intermediaries is not the most critical property to determine the applicability of blockchain in the public service.

(6) Digital Native assets

Blockchain is considered as more valuable if it works with native digital assets that can be successfully represented in a digital format. Some decision trees are even excluding the use of blockchain in case of physical assets.[120] In a smart city context, this condition might be problematic when blockchain is used to manage sensor records or other types of non-digital/physical assets. Most of the cases consider the use of digital assets valuable. Only 30 per cent of the cases are not working with digital assets. Except for native assets such as Bitcoin, a higher risk of security in the system is undeniable whether it concerns digital assets or digitalized physical assets. Research has allowed potential solutions to bridge the gaps relating to breach of security. Some examples of successful research endeavours include the careful designing of the interface, particularly in the case of voting (Active Citizen use-case) or tickets (*Stadjerpas* use-case) or health records (Healthy use-case). However, in general, more investigation is required in this field. Overall, the applicability of blockchain for smart city initiatives that are not using native digital assets is not in question. Under these circumstances, it could be more challenging in terms of security, and it could be worth exploring other solutions within this domain.

(7) Permanent record of the information

Blockchain is recommended if it is necessary to have a permanent record of the information. All parties involved in a new solution need to agree on how the state of the digital asset will be handled/managed in the new business process prior to any development occurring. If an unalterable record is superfluous or counterproductive, for example, in a situation in which the need to delete information is critical, then blockchain is not recommended.[121] Only 25 per cent of the use-cases reported the permanent record as not important. In those specific cases, it does not have a specific impact; however, in other situations, it might be an issue. Nevertheless, whether or not it is possible to maintain a permanent record, the applicability of blockchain will not be affected. It will show that blockchain is not the optimum solution for that use-case, which could be critical criteria to consider in the context of cities with limited capabilities.

(8) Contractual relationship

Decision models consider that blockchain is more useful if the business problem is the management of contractual relationships or value exchange.[122] It is a use-case with a smart contract. Blockchain is recommended in this type of situation given the features of security, and the record of the transactions process and states. Smart contract is widely used. However, 70 per cent of the cases consider that it is not necessary to implement a contractual relationship. Indeed, smart contracts are relevant applications of blockchain technology, however they are not essential. The most important question here is to determine whether a contract on blockchain operates the same way as a legal contract. Studies highlighted that technology does not have any legal effect. The suitability of blockchain here is not in question.[123] However, the implementation of blockchain without a clear legal or regulatory framework could jeopardize the application of the blockchain at great cost for the city.

(9) Transaction states record

Blockchain is considered as useful if the transactional relationship is required to provide and record the state of the transactions. This is in alignment with the immutability principle of blockchain technology. Unanimously, the use-cases consider it essential to record the state of the transaction. However, different blockchains have different ways to preserve their history and transaction states. These differences are fundamental to the specific characteristics of each type of blockchain. This dimension is directly related to one of the most important features of blockchain, however it does not question the applicability of blockchain. In general, this is one of the most researched features that motivate public services in exploring blockchain technology.

(10) Sensitive data record

Personal and sensitive data should not be stored in the blockchain, since it conflicts with data protection regulations.[124] Blockchain is designed to facilitate the sharing of data. In the public blockchain, all the transactions are transparent and visible, which may increase trust. However, the transparency could be a problem when information is personal, sensitive and contains confidential data. Public organizations and municipalities are the entities that are collecting and storing a large volume of personal and sensitive information about the residents. Individuals have little or no control over the data that are stored about them and how it is used. Blockchain is presented as a solution to achieve a balance between data privacy and the need to control better access to records and private information.[125] However, the storage and sharing of sensitive issues vary depending on the type of blockchain. To overcome the challenge, most of the use-cases are adopting a private permissioned blockchain and advanced cryptography using zero-knowledge proofs allowing the institutions to transact on public blockchains while still protecting sensitive data. Research and development on public blockchain are progressively providing solutions to the issue of confidentiality. Sensitive data record is an important issue that does not question the blockchain applicability but determines the adequate type. A possible solution is to store confidential, sensitive or personal data off-chain and use a hash reference to keep access to the original data.

(11) Deleting data

Deleting data is an important characteristic and specificity that plays a critical role in blockchain applicability. Surprisingly, 80 per cent of the cases consider the possibility to delete data necessary, which is contradictory to the principle of immutability. It is technically impossible to delete data from blockchain. From a legal perspective, it might cause an issue. In the European context, it is considered as the main “GDPR-blockchain paradox”, given the “right to be forgotten”. Several studies are currently being undertaken to challenge the immutability of blockchain technology or to adapt the technology to comply with the regulatory frameworks. Research advancement showed that it is possible to delete full nodes of undesirable data while continuing to store and validate most of the blockchain.[126] Even though the requirements of deleting data is not preventing blockchain applicability for public service and cities, for the time being it does limit the options in terms of blockchain type and most specifically for the use-cases that require the recording and sharing of sensitive data.

(12) Writing access

Blockchain is recommended when all the entities and users have to write transactions into the system.[127] The Word Economic Forum model (2018) considers it critical to the application of blockchain. The multistakeholder complexity of smart city initiatives requires to be more specific and to link this question directly to the degree of trust among the participants and anonymity in blockchain.[128] The requirement of shared writing access is mitigated among the uses-cases. Some studies showed that in the context of smart city initiatives, shared writing access is the most important criteria if there are multiple parties involved.[129] These parties might assume similar roles or different roles (e.g. readers/writers/validators). This condition is critical in the decision to adopt blockchain. It will also define the type, design and network architecture of blockchain for each situation.

(13) Good performance for the transactions

Blockchain performance is presented as one of the main challenges of the applicability of blockchain. It also impacts the scalability and performance. It is considered as a temporary challenge that is being monitored carefully. Experts are emphasizing that the performance is no longer an issue, and the benefits of blockchain are overcoming its temporary challenges. Consequently, the need for good performance of the transaction does not constitute a barrier to the applicability of blockchain technology for cities, but it depends on the numbers of users. However, it will help to define the design of the blockchain architecture if some properties of the permissioned and permissionless blockchains are contrasted.

(14) If it is necessary to record non-transactional data

Blockchain is recommended when the lack of trust is related to the storage of transaction records. The parties cannot trust the others to always accurately record and report events which explain the need to log non-transactional data systematically. More than half of the cases consider it necessary to record non-transactional data. However, if the storage of non-transactional data is required, it is not advisable to use blockchain.[130] Recent progress in research and development demonstrated that blockchain could also record non-transactional data such as title records, trademark and patent information, minutes of meetings, calendar of entries, annual reports and travel log etc.[131] Even though it is not highly recommended to use blockchain for non-transactional data due to the risk of reaching maximum memory, it remains possible. This concern is addressed, and research on blockchain showed that it is possible to add a data layer to the blockchain.

These 14 blockchain dimensions refer to three different aspects of blockchain suitability: the process, the design and the technology. Despite these dimensions being commonly used in different decisions models and trees, it can be deduced from Table 9 that none of the cases fully complies with the 14 selected variables. Does this mean that blockchain is not the right technology for these use-cases? The answer is "no".

Research about blockchain technology is continuously progressing. With regard to the suitability of blockchain for cities, it can be concluded that there is a large span of applicability and opportunity for this innovative technology.

It is very difficult to have a one-size-fits-all solution for B4C; however, blockchain technology could be a relevant and suitable technology to explore if there is (1) a need to store information and data, (2) if multiple parties are involved, and (3) if it engages trust among the involved parties (4) if it concerns transactions or transfer of value. All the other variables of the suitability of blockchain technology will help the city to obtain a more in-depth analysis of the process, the design and the technology. Furthermore, it will help to navigate, evaluate and assess which type of blockchain, whether it is an optimal solution, as well as to compare it to alternative technology. In the specific context of blockchain for cities, complying only with the suitability of blockchain is not sufficient; it requires a contribution to the smartness and the sustainability challenges of cities in priority as well, and depends on the specific context of the city. It is critical to ace the suitability test if there is a clear need to solve a problem or seize an opportunity identified, and one where blockchain could be useful.

6. Conclusion and key considerations for blockchain for cities

Blockchain technology as a foundational form of innovation is among the most trending technologies attracting more interest for future urban development initiatives and smart sustainable city efforts. The public sector and more specifically public service is where blockchain could have the most impact.

As presented in this report, several cities have started adopting and developing pilots of blockchain-based smart city efforts. However, many concerns remain regarding the technology and its understanding, as well as questions on its applicability to future cities projects. This report intended to reduce these gaps by leveraging knowledge from the scientific literature in the field, from the analysis of concrete use-cases and experience challenges, opportunities and lessons learned, as well as from experts, to provide research-driven policy recommendations.

Bearing the above in mind, this report looks to address the key considerations in exploring blockchain technologies as a part of smart city initiatives. These considerations are critical for municipal managers, as well as decision- and policy-makers to reflect on and integrate when considering smart cities initiatives that involve the applications of blockchain. They are based on the findings, use-cases and other experiences of blockchain technology adoption by the public service and government.

(1) Building a Blockchain Smart sustainable city Ecosystem

Blockchain-based smart city initiatives are complex and compel the involvement of multiple stakeholders, and require different types of expertise (IT, finance, auditing, development, programming). The development of a multistakeholder approach and collaboration, encompassing the local government entities, regulators, start-ups, banks and others is critical to the success of blockchain projects.

Building a blockchain ecosystem in the city is considered one of the main success factors for blockchain adoption. Public-private-partnerships with local start-ups and organizations or the development of innovation labs with blockchain capabilities and related technologies, which could be collaborations between universities, municipalities and local start-ups or private companies, are drivers to the development of successful use-cases of blockchain for cities.

Moreover, regional programmes and collaboration between cities such as the Intereg BLING programme, composed of 13 partners in the North Sea Region, are good examples of blockchain ecosystems that create value and increase success. Cities from industrialized countries could support the efforts of cities from developing countries to capitalize on blockchain technology through aid programmes, technology and knowledge transfer, and support to policy-makers.

The city must play a key role in promoting the ecosystem prosperity and new business opportunities, to orient initiatives toward generating sustainability, inclusiveness and public value for all stakeholders, and to avoid producing or reinforcing urban inequalities. Experts highlight the local government "leadership" role in initiating consortia and in building an ecosystem to favour collaboration and partnership for successful blockchain adoption and fostering innovation in cities. Implementing PPPs and cooperation between blockchain actors, and envisioning a strong role for government as part of such consortia are critical drivers of the blockchain development. However, these constitute a challenge for cities and municipalities that often have never experienced this type of role. It is a significant paradigm shift and requires a complete change of mindset, particularly when it comes to collaboration with the private sector and accommodating the varying interests of a multitude of stakeholders. This type of model requires collaborative governance mechanisms, in the face of the potentially disruptive characteristics of blockchain and the involvement of multiple actors in PPPs, which is challenging for the public sector. There are favorable reasons for cooperation: the actions proposed would strengthen the chances of success for blockchain applications to support a wider set of socially and environment valuable outcomes.

(2) Defining a Governance Model

One of the main challenges in developing a smart city or community initiative is defining a common vision between different stakeholders. There will be competing ideas of what matters in the city, which challenges to prioritize and what goals to pursue. As long as different stakeholders are pursuing different goals and have conflicting interests, they will face many barriers in the process. The governance model for the solution to be implemented must be defined considering the smart and sustainable benefits with the blockchain application. A wider understanding of the sustainable development goals and how other cities or communities are working toward them will enable stakeholders to take a long-term view and execute projects with more distant considerations.

Furthermore, governance and leadership readiness, a dominant challenge in itself within public sector organizations and blockchain technology is adding a layer of complexity. Leadership, particularly in championing innovations, is key to the successful adoption of disruptive technologies such as blockchain technology. However, studies demonstrate that the lack of knowledge and understanding of the technology at the top management level in general, and more especially in the public sector, are hindering blockchain-based initiative and the realization of the potential strategic value of blockchain.

Smart city initiatives need to be governed. It is essential to develop and define an appropriate governance framework that sets out the roles and liabilities of respective parties, the applicability of law in case of disputes, decision-making limits and processes of authorized participants in the network, as well as steps to mitigate market manipulation and unfair practices.

The governance model must be clearly defined and should include procedures for changing itself. The model is likely to need to be adapted regularly to integrate new regulations, the acquisition and integration of new resources, any re-engineering of transactions and systems, and the development of new skills and competencies as the initiatives are evolving.

(3) Prioritizing sustainability and smartness in technology and innovation adoption

Smart city initiatives and programmes are dominated by technocentrism that prioritizes technology-based solutions over needs-driven solutions and sustainability. The concept of blockchain for cities runs the risk of reducing smart sustainable cities to technological capabilities and development, as well as limiting smart cities rankings to a single dimension. This is directly linked to the misconception that increasing city smartness might cause the diversion of limited public fund investments away from pressing local needs towards smart initiatives. Smart city initiatives are often led by engineering, construction, consultancy and technology companies that influence the city decision making toward solutions that may be disconnected from the specific needs, priorities and context of the city. This has sometimes led to a greater concern for economic growth and technology innovation, than for environmental sustainability or social impacts and could create more harm to the environment and society. However, innovation should also be directed to environmental sustainability and inclusion. It could be also important to better price externalities and tax on pollution and waste. B4C could be a relevant tool for this specific purpose and it could exert pressure on companies to choose solutions and activities that are less polluting, for example.

The urban-centre transformation with blockchain technology is mainly fostered by hype about blockchain and the pursuit of technological innovation beyond the real need for the technology. Among the use-cases lesson-learned, was that purposeful evaluation of blockchain-based transformations is important. Every process must be evaluated critically, based on whether blockchain-based solutions can potentially yield benefits, because blockchain is still in an early stage of development and different types of solutions exist. It is not surprising that many frameworks that guide the use of blockchain start with a critical evaluation of whether the technology is the right solution to be considering.

It is also important to highlight that blockchain technology in smart city projects does not perform in isolation, rather it has to operate in combination with other technologies such as IoT or AI, as well as interfacing with existing systems, which increases the need to question which technologies are appropriate to develop smartness and sustainability in cities. Although a new, technology-driven project may be useful as a testbed to build capabilities for future applications, it will not create city or community smartness and sustainability alone. It is more important to consolidate smart, sustainable policies in order to overcome the pro-technology and anti-technology dichotomy and carefully plan the technology investment by better aligning the relationship between the city, businesses, the residents and the technology. It is the responsibility of policy-makers and city managers to create value for the public and to ensure a culture of sustainability of the society and the environment.

(4) Complying with the standards and regulation

The biggest challenge in applying blockchain is related to the regulation uncertainty that impacts blockchain development decisions at different levels. The innovative aspects of blockchain, such as being public and permissionless, assuring anonymity and immutability along with automation, are at the root of legal and regulatory challenges. These features of blockchain make it difficult to perform basic legal functions, such as to ascertain liability, to determine what law is applicable in a particular situation, or to carry out regulatory monitoring and enforcement.

Compliance with regulations and law is critical in the context of smart sustainable cities and in government and public service in general. Undeniably, regulation and policy compliance could be insurmountable barriers to using blockchain if the project is not adequately aligned with the regulations and policies of the country; so this must be established before deciding to use blockchain. Even when there are indications that a regulation or policy will be updated and the changes will support the process implemented in blockchain, there is the risk that the update will not specifically address what is expected, or that it will not be approved within the expected timeframes.

Blockchain is an interesting tool to help achieve compliance by coding rules and regulations. Nonetheless, it might also create rigidity due to the immutability of code and data, making it difficult to accommodate inevitable changes in regulations. Smart contracts, for example, are considered feasible or applicable only under limited and circumscribed conditions, such as when there is no need for dispute resolution. The automation and disintermediation of smart contracts can, in some cases, be understood as representing a legal contract however it has created much confusion. Although smart contracts can be used to write "tamper-proof" agreements, it does not mean that they have legal value, depending on the case and the applicable law. Overall, regulators and policy-makers need to find a balance between taking advantage of the innovation of blockchain and complying with applicable law and other public protection aspects.

(5) Ensuring Data protection and privacy

Complementing the regulatory uncertainty, there are also concerns about data protection and privacy. Smart solutions often rely on personal information available in city platforms, which can be used to create profiles of citizens. This raises the question of the protection of personal information. The challenge for cities and communities is to ensure that the legal frameworks and appropriate technical measures are in place to manage risks and ensure that there is enough public trust to support these initiatives. Data protection and privacy legislation vary from country to country.

In Europe, for example, there is a strict requirement to comply with the General Data Protection Regulation (GDPR). It is important to highlight that GDPR compliance is not about the technology, but about how the technology is used. Consequently, the requirements depend on the case and the specific application. The tensions between the use of blockchain and GDPR requirements revolve around three main issues: the identification and obligations of data controllers and processors; the anonymization of personal data; and the exercise of some data subject's rights. These issues have not been settled conclusively by the data protection authorities, the European Data Protection Board (EDPB), or in court. Regulators need to understand each blockchain use-case and the technology characteristics, which can vary tremendously from one case to another.

For countries outside Europe, the specific laws need to be understood in context. In countries where data protection legislation is not yet in place, or is less developed, there is an even greater need for the public sector to think through the possible impact of blockchain implementations on individual privacy. It is essential to either identify or provide, and work within, an ethical and regulatory framework for data collection, use and sharing. There is a great risk of misuse and breach when implementing a blockchain, particularly when data could be collected from different sources, some of which may be anonymous. When navigating these risks, it is important to analyze how user value is created, establish how data are used and ascertain if blockchain could be the best solution. It may be necessary to avoid storing personal data in the blockchain, to make use of data obfuscation, encryption and aggregation techniques to anonymize data, or to innovate in other ways to ensure transparency with the users.

(6) Acquiring knowledge and developing capabilities

There is a clear need for decision-makers, and those contributing to change in the public sector, to gain a better understanding of the technology, in order to comply with regulations, define standards, protect citizens' rights and ensure adoption. There is also a need to acquire knowledge related to business models, technical choices, and the governance of blockchain technology for its successful implementation. The complexity, the integration with legacy systems, the cost effectiveness and resource efficiency are inherent characteristics of blockchain-based smart city initiatives.

Decision- and policy-makers are often alert about these issues and particularly sensitive to the cost aspect. One of the challenges of smart solutions is the need to finance its implementation and operation. Currently, many smart city initiatives are funded from government sources, either at the local or national level; this is often justified by the prospect of increasing revenues or decreasing costs associated with public services. However, smart solutions present a great pressure for the public budget. Other smart projects are financed by public-private partnerships, by the private sector or by donors. For cities to access a wider pool of funds, business models need to be explored that encourage the private sector and other sources to be part of these initiatives.

Beyond the cost, there are concerns about other parameters such as the capacity, the scalability, the update and upgrade requirements of the technologies that increase costs, as well as the risks of lock-in and the risk to security. For many cities and communities, the deep technical skills needed to benefit from most of these smart technologies are not available, or are only available at a very high cost. Even the skills needed to run low-level ICT infrastructure reliably could be lacking in many contexts. These concerns are amplified with blockchain-based projects. Skills in designing and running blockchain projects, managing changes and communicating effectively are also needed for successful smart city initiatives. Consequently, there is a need for public service training and development programmes as local governments invest in pilot projects and knowledge development to better comprehend the potential of the technology. Such training and development can be facilitated through collaboration between the public and private sectors. Skills and capabilities development will reduce the complexity associated with the technology, and when combined with public private partnerships and cooperation initiatives, will solve some of the challenges of blockchain adoption, such as immaturity, scalability, interoperability, and the cost of the technology.

Low- and middle-income countries face a greater challenge in creating the conditions appropriate for the use of blockchain technologies. Here, there needs to be greater investment and development of basic digital infrastructures (reliable power supply, connectivity, sufficient bandwidth, IoT and other technologies), education and capabilities to support innovators and regulators by sharing and building skills through local and regional partnerships. These efforts will enable the development of initiatives using blockchain that could support cities, along with rural areas and communities, to face economic, social and environmental challenges in line with the SDGs.

Recommendations:

City administrators, policy-advisors and decision-makers should…

- Approach blockchain with caution as it is a technology with interesting possibilities that is not yet fully understood.
- Build, over time, a blockchain for cities ecosystems in collaboration with other stakeholders in the city or community, including businesses, academic institutions, financial institutions, spaces for innovation, technical experts, community bodies and residents, as well as inter-city cooperation.
- Develop within the ecosystem, expert capacity as well as a wider understanding of the technology in terms of what blockchain and smart contracts are, their potential and risks for the community and individuals, and how they could be viewed within the local legal frameworks.
- Identify or create an appropriate regulatory and ethical framework to govern blockchain initiatives, which addresses legal matters, takes into account data security and privacy, and protects against stakeholders acting in their interests in a manner that could constitute a threat to sustainability.
- Focus on planning that takes a need-driven approach – that is, seek projects that address real local needs and is aware of the risks associated with an exclusively technology-driven approach to smart blockchain-based initiatives and the prevalence of hype in driving new technology adoption.
- Be sensitive to the technological and digital exclusion of parts of society in urban areas or within certain communities and assess use-cases for their potential to exacerbate or increase such inequalities.
- Prioritise use-cases with the potential for positive impacts on sustainability, particularly from a social and environmental perspective, plan to measure the impacts and closely monitor positive and negative outcomes during implementation.
- Explore within the ecosystem, innovative funding mechanisms to support innovative projects.
- Ensure that initiatives undertaken are closely monitored and reported on and that the outcomes and lessons learned are shared within the ecosystem.

Appendix 1: Glossary

Category	Term	Acronym	Meaning
Blockchain	Address		Nickname of the public password that is normally obtained by a hash function
Blockchain	Asymmetric key cryptography		Asymmetric key cryptography
Blockchain	Block		http://blockchainhub.net/blockchain-glossary/
Blockchain	Blockchain		https://www.economist.com/briefing/2015/10/31/the-great-chain-of-being-sure-about-things https://hbr.org/2017/01/the-truth-about-blockchain Raval.S (2016). Decentralized Applications: Harnessing Bitcoin's Blockchain Technology. O'Reilly Media, Inc.. Retrieved from http://kddlab.zjgsu.edu.cn:7200/research/blockchain/OReilly.Decentralized.Applications.Harnessing.Bitcoins.Blockchain.Technology.pdf
Blockchain	Blockchain		In addition, there are public blockchain nets (like Bitcoin, Ethereum, etc.) where everyone can join it (i.e. be part of the net activities). There are private blockchain systems (like Quorum, HyperLedger fabric, etc.) where you can operate in the net in private mode so that the access to the net and operations are controlled by one or several actors (but it is not open to everybody). There are permissioned private nets where you need permissions from the administrators to participate and operate into the net and semi-permissioned private nets where is some open information and additional information must be permissioned by the administrators in case you want to operate. In private networks there are not public miners nor are there rewards as in the concept of a public network, where the miner gets profits when they engage in the mining activity.
Blockchain	Bounty		Reward
Blockchain	Consensus Algorithm		Consensus Algorithm
Blockchain	Digital Identity		The identity belongs to each user and they can agree to use it for a single operation one by one and just for one specific use.
Blockchain	Exchange		https://www.nortonrosefulbright.com/en/knowledge/publications/e383ade6/cryptocurrency-exchanges-and-custody-providers-international-regulatory-developments
Blockchain	Flat money		Trust money
Blockchain	Fork		https://academy.binance.com/blockchain/hard-forks-and-soft-forks
Blockchain	Full node		Validator node/complete node
Blockchain	Gas		Cost to operate into the blockchain net
Blockchain	Hard cap		Maximum catchment of an ICO
Blockchain	Hard fork		Antonopoulos, Andreas (2017). Mastering Bitcoin: Programming the Open Blockchain (2 ed.). USA: O' Reilly media, inc. p. Glossary. ISBN 978-1491954386.
Blockchain	Hash function		https://academic.microsoft.com/topic/99138194/publication/search?q=Hash%20function&qe=And(Composite(F.FId%253D99138194)%252CTy%253D%270%27)&f=&orderBy=0
Blockchain	Hash Table		https://www.cs.cornell.edu/courses/cs3110/2020sp/textbook/eff/hash.html
Blockchain	Light node		Subordinated node
Blockchain	Mempool		List of transactions that are not confirmed yet
Blockchain	Merkle root		Hash of hashes. It is the root of the Merkle tree
Blockchain	Merkle tree		https://blockchainlabs.ai/the-merkle-tree/
Blockchain	Mining		To find the solution to the algorithm that allows adding a new blockchain, usually with a reward in the form of cryptocurrency that will be owned by the miner who finds the solution
Blockchain	Mining pool		https://www.blockchain.com/pools
Blockchain	Orphan block		When a blockchain block is not used as there is another block with the same number that has got more blocks after
Blockchain	Peer-to-peer	P2P	https://dictionary.cambridge.org/dictionary/english/peer-to-peer
Blockchain	Private Key		It is the secret digital identifier with asymmetric cryptography to encrypt and decipher the content. It is essential to (1) create a wallet, (2) access it and use it, and (3) to transact in the blockchain.

Category	Term	Acronym	Meaning
Blockchain	Proof of Stake	PoS	https://academy.binance.com/blockchain/proof-of-stake-explained
Blockchain	Proof of Work	PoW	https://academy.horizen.global/technology/expert/proof-of-work/
Blockchain	Public Key		It is an alias associated with a private key generated by a cryptographic function. Normally the public key is finally converted into an Address by means of a hash function. The public key reliably identifies the party that has made the transaction, respecting the privacy of their encrypted data.
Blockchain	Routing		Wang.H, Cen.Y, Li.X (2017). Blockchain Router: A Cross-Chain Communication Protocol
Blockchain	Security Token		Token that pays dividends and can be seen directly associated with financial speculation about the value of the company (stock).
Blockchain	Simplified Payment Verification	SPV	https://electrum.readthedocs.io/en/latest/spv.html
Blockchain	Smart Contract		http://blockchainhub.net/smart-contracts/
Blockchain	Soft Fork		https://academy.binance.com/blockchain/hard-forks-and-soft-forks
Blockchain	Swap		Unlike fork, in the case of the swap, a new currency must be created from scratch. It is done when important measures have to be implemented that have no place in a simple update of the code (as in the case of NEO or EOS, by changing the tokens generated on Ethereum by Altcoins issued on the propriety blockchain of each project).
Blockchain	Token		Unlike Altcoin, it is a cryptocurrency built on an existing blockchain (e.g. Ethereum).
Blockchain	Transaction	TX	https://www.blockchain.com/charts/n-transactions
Blockchain	Transaction fee		https://support.blockchain.com/hc/en-us/articles/360000939903-Transaction-fees
Blockchain	Transaction Output	TXO	https://support.blockchain.com/hc/en-us/articles/360040028192-Anatomy-of-a-Bitcoin -Transaction
Blockchain	Transaction per second	TPS	https://academy.binance.com/glossary/transactions-per-second-tps
Blockchain	Transaction routing		https://arxiv.org/pdf/1809.05088.pdf
Blockchain	Trustless		https://academy.binance.com/glossary/trustless
Blockchain	Unspent Transaction Output	UTXO	https://academy.binance.com/glossary/unspent-transaction-output-utxo
Blockchain	Utility Token		A token with a specific utility within a platform or ecosystem ideally provides added value. It does not pay dividends or be associated with “shares” of a company. Example: Flixx, BAT, etc.
Blockchain	Wallet		https://www.aprio.com/whatsnext/what-is-a-blockchain-wallet/
Blockchain	Whitepaper		https://www.investopedia.com/terms/w/whitepaper.asp
Smart City	AI		https://chist.org/artificial-intelligence/
Smart City	API		“Application programming interface”. It is a set of definitions, protocols and tools that allows different software and hardware to integrate with one another
Smart City	Big data		Big data refers to the collection of data sets that are so large and complex that it is difficult to capture, transfer, store, process and interpret with traditional data processing applications. It allows for rich information to be derived on a range of variables such as real-time traffic conditions, air pollution and energy use.
Smart City	Citizen-centric approach		The delivery of services based on solving the needs and challenges of the people they serve-used as a way to increase public satisfaction, improve efficiency and reduce costs.
Smart City	City as a service		This combines infrastructure-as-a-Service (IaaS) and Software-as-a-Service (SaaS) technologies for use as common, city-wide platform for the deployment of the integrated smart city technologies (along the lines of operating system for the city).
Smart City	Hyper-local data		Data gathered or shared within a very tight geographical area, such as a street of an apartment block.
Smart City	IoT		Global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies. Source: ITU-T Y.4000/Y.2060 (06/2012)

Category	Term	Acronym	Meaning
Smart City	LPWAN		Low Power Wide Area Network (LPWAN) is a type of wireless communication wide area network. It facilitates long-range communications at a low bit rate between connected objects (along the lines of a network through which city infrastructure can communicate).
Smart City	Multi-modal transport		Simply a system that facilitates a variety of transport options, such as cycling, bus, light rail train, ferry or walking.
Smart City	Open Data		Data that is freely available for everyone to use without copyright patent or other restrictions.
Smart City	Platform as a service		A category of cloud computing services that provides a platform to facilitate the development and management of digital applications.
Smart City	Predictive analysis		The use of statistical techniques such as predictive modelling, machine-learning and data mining to analyze data and make predictions about the future.
Smart City	Sensors		An electronic component, module or subsystem used to detect events, triggers or changes in the surrounding environment.
Smart City	Situational awareness		Awareness of the surrounding environment or the perception of environmental elements and events and understanding of their meaning. For example: autonomous vehicles have situation awareness.
Smart City	Small data		Small data refers to highly specific fragments of data collected by a large number of sensors. The data, such as air quality measurements, are of small size but very precise in terms of time and place.
Smart City	Smart City APP		A type of smart city technology or system that has a specific function: such as smart street lighting, smart bins or smart drains.
Smart City	Smart city infrastructure		The integration of smart technologies into the fundamental systems that serve a city or municipal area.
Smart City	Smart city streetlighting		Streetlights that can be controlled wirelessly to save energy and reduce maintenance costs. The wireless network controlling street lighting can also be expanded to connect sensors that gather data on weather conditions, air pollution and more.
Smart City	Smart drains		Drains equipped with sensors that send alerts when they are in danger of over-sitting or overflowing, and collect fill rate that can be used for highly efficient predictive cleaning operations.
Smart City	Smart grid		An enhanced electrical grid that uses analogue or digital technology to gather and act on information such as supplier or consumer behaviour to automatically improve efficiency and sustainability of electrical distribution.
Smart City	Smart networks		A network that contains built-in diagnostics, management, fault tolerance and other capabilities to prevent downtime and maintain efficient performance.
Smart City	Smart parking		A system that helps drivers find vacant parking spaces using sensors and communication networks.
Smart City	Smart Sustainable Cities		A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects. Source: Recommendation ITU-T Y.4900
Smart City	Smart waste		Waste receptacles, such as city litter bins and commercial waste bins, equipped with connected sensors that collect and share data on, for example, the need for and frequency of waste collections.
Smart City	Sustainability		The maintenance and betterment of the ecological, social and economic health of a city.
Smart City	Traffic adaptive lighting		With this type of smart street lighting, the brightness of the street varies electronically based on real-time traffic flow data.
Smart City	Ubiquitous cities (U-cities)		A hyper-connected smart city: all information systems working in the city are linked and virtually everything is connected to a cohesive city platform.
Smart City	UNB Network		A type of LPWAN pioneered by Telensa to connect smart city sensors and controls at low cost for the rapid integration of smart city applications.
Smart City	Unstructured data		Information that lacks pre-defined data model for interpretation or analysis

Category	Term	Acronym	Meaning
Smart City	Urban data platform		Provides a cohesive digital environment for aggregation of data across multiple geographic areas or civic functions of the city (along the lines of a single platform for collecting and sharing city data).
Smart City	Wireless lighting		Lighting that can be controlled wirelessly. See smart street lighting
Smart City	Workability		A measure of viability of a smart city application relating to economic competitiveness and productivity.

Appendix 2: B4C use-cases analysis

Table A.1 (I): General context of B4C use-case

General Characteristics	Use Cases					
	Weekend Fairs	Active Citizen	Land Titling	Energy systems	Debt relief	e-vote for cell towers
Status of the project	Implemen-tation in progress	Solution implemen-ted	Solution imple-men ted	Implemen-tation in progress	Implemen-tation in progress	PoC concluded
City/ Community	Moscow	Moscow	Georgia (Country)	South-Holland	LaHague	South Tyrol
Government level involved	Federal/ Provincial/ Local	Federal/ Provincial/ Local	National/ Local	Federal/ Provincial	National	Federal/ Provincial/ Local
Main stakeholders involved	Federal/ Provincial Government	Federal/ Provincial Government	Public and Private organi-zations	Public and Private organi-zations	Public and Private organi-zations and University	Public and Private organizations
How important is transpa-rency in the system?	High	High	High	High	High	Medium to high
How important is it to assure privacy of the users?	Not important	Not important	Medium	High	High	Medium to high
Definition of Governance Model	No	No	Yes	Yes	Yes	Yes

Table A.1 (II): General context of B4C use-case (end)

General Characteristics	Use Cases						
	Digital Democracy	Claim verifi-cation 18+	Financial Emergency	Healthy	Stadjerpas	BlinG	BlinG
Status of the project	Pilot	Prototype	PoC concluded	PoC concluded	Solution implemented	PoC concluded	PoC concluded
City/ Community	Barcelona	Amsterdam	Tilburg	North Sea Region	Groningen	Oldenburg	North Sea Region
Government level involved	Local	Local	National	Local	Local	Federal/ Provincial/ Local	Local
Main stakeholders involved	Public and Private organiza-tions, Research Institutes and Universi-ties	Public and private organizations, Research Institutes and Universities	Public government	Public Organizational Knowledge institution	Public and Private organizations	Federal/ Provincial/ Local government	Local government Private company knowledge institution
How important is transparency in the system?	Not available	Not available	Low	High	Medium	High	High
How important is it to assure privacy of the users?	High	High	High	High	High	High	High
Definition of Governance Model	Not available	Not available	Not yet	No	No	No	No

Table A.2 (I): Sustainability of B4C use-cases

Sustainability	Use Cases					
	Weekend Fairs	Active Citizen	Land Titling	Energy Systems	Debt relief	e-vote for cell towers
Does the project contribute to economic sustainability? Which area?	Business sustainability	No	Employment business sustainability	Household income and expenses	Household income and expenses business	No
Does the project contribute to environ-mental sustainability? Which area?	No	No	Green Space, ecosystems and heritage Others: Ecological footprints, natural catastrophes, level of exposure to natural and industrial risks, consumption of equitable products, urban	Energy Transport Air quality	No	No
Does the project contribute to social and institutional sustainability? Which area?	Social and community services	Social and community services	Demographics Housing Security Well-Being Social and community services Governance Expenses and public administration	Housing Well-Being	Demographics Housing Education Health Well-Being Social and community services Governance Expenses and public administration	Governance
SDG?	SDG 8 SDG 10	SDG 11	SDG 8 SDG 9 SDG 10 SDG 11 SDG 16 SDG 17	SDG 7 SDG 11 SDG 12 SDG 17	SDG 1 SDG 3 SDG 10 SDG 11 SDG 16	SDG 9

Table A.2 (II): Sustainability of B4C use-cases (end)

Sustainability	Use Cases						
	Digital Democracy	Claim verification 18+	Financial Emergency	Healthy	Stadjerpas	BlinG	BlinG
Does the project contribute to economic sustainability? Which area?	No	Not available	House-hold income and expenses	None of these	Household income and expenses	Businesses	Businesses
Does the project contribute to environmental sustainability? Which area?	No	No	No	No	No	Green Space, ecosystems and heritage Waste Others: Ecological footprints, natural catastrophes, level of exposure to natural and industrial risks, consumption of equitable products, urban	Transport
Does the project contribute to social and institutional sustainability? Which area?	Social and community services	Not available	Governance Expenses and public administration	Health Well-Being	Social and community services Expenses and public administration	Social and community services	Health Well-Being Expenses and public administration
SDG?	Not available	Not available	SDG 1 SDG 16	SDG 3	SDG 1 SDG 11	SDG 9 SDG 11	SDG 3 SDG 8 SDG 13

Table A.3 (I): Smartness of B4C use-cases

Sustainability	Use Cases					
	Weekend Fairs	Active Citizen	Land Titling	Energy Systems	Debt relief	e-vote for cell towers
Change in the relationship between Stakeholders and in their role	No change for stakeholders	No change for stakeholders	By including new stakeholders By changing what the stakeholders do By changing the frequencies of interactions between the stakeholders By changing the nature of interactions between the stakeholders By changing the power dynamics between the stakeholders	By including new stakeholders By changing what the stakeholders do By changing the frequencies of interactions between the stakeholders By changing the nature of interactions between the stakeholders By changing the power dynamics between the stakeholders	By including new stakeholders By changing the nature of interactions between the stakeholders By changing the power dynamics between the stakeholders Some other change for stakeholders	By changing what the stakeholders do By changing the frequencies of interactions between the stakeholders By changing the nature of interactions between the stakeholders By changing the power dynamics between the stakeholders
Smart Domains	None	None	Smart Governance Smart Economy Smart Mobility Smart People Smart Living	Smart Governance Smart Economy Smart Mobility Smart Environment Smart People Smart Living	Smart Governance Smart Economy Smart People	Smart Governance
Innovative-ness	Innovative service(s) offered innovative service delivery	Innovative service delivery	Innovative service(s) offered Innovative strategy (planning) processes Innovative regulations (laws, policies) Innovative service delivery Innovative partnerships Effective, transparent governance for fighting corruption	Innovative service(s) offered Innovative regulations (laws, policies) Innovative partnerships	Innovative service(s) offered Innovative internal processes Innovative regulations (laws, policies) Innovative service delivery Innovative partnerships	Innovative service(s) offered Innovative internal processes Innovative regulations (laws, policies) Innovative service delivery
Are the values underpinning this project/ solution related to?	The provision of better city infrastructure and services improving city governance and engaging citizens in governance	The provision of better city infrastructure and services Entrenching civic values, supporting social inclusion or equity and fairness	The provision of better city infrastructure and services Entrenching civic values, supporting social inclusion or equity and fairness Improving city governance and engaging citizens in governance	The provision of better city infrastructure and services Entrenching civic values, supporting social inclusion or equity and fairness Protecting the environment and sustainability	The provision of better city infrastructure and services Entrenching civic values, supporting social inclusion or equity and fairness Improving city governance and engaging citizens in governance	The provision of better city infrastructure and services Improving city governance and engaging citizens in governance

Table A.3 (II): Smartness of B4C use-cases (end)

Sustainability	Use Cases						
	Digital Democracy	Claim verification 18+	Financial Emergency	Healthy	Stadjerpas	BlinG	BlinG
Change in the relationship between Stakeholders and in their role	Not Available	Not Available	By changing what the stakeholders do By changing the nature of interactions between the stakeholders	By changing the nature of interactions between the stakeholders	No change for stakeholders	No change for stakeholders	By including new stakeholders By changing what the stakeholders do By changing the frequencies of interactions between the stakeholders
Smart Domains	Not Available	Not Available	Smart Governance Smart People	Smart People Smart Living	Smart People	Smart Governance	Smart Economy Smart Mobility Smart People
Innovativeness	Not Available	Not Available	Innovative service(s) offered Innovative internal processes Innovative partnerships	Innovative service delivery Innovative partnerships	Innovative internal processes Innovative service delivery	Innovative internal processes Innovative service delivery	Innovative service(s) offered Innovative internal processes Innovative service delivery
Are the values underpinning this project/ solution related to?	Not Available	Not Available	Entrenching civic values, supporting social inclusion or equity and fairness Improving city governance and engaging citizens in governance	None of these	The provision of better city infrastructure and services Entrenching civic values, supporting social inclusion or equity and fairness	The provision of better city infrastructure and services Entrenching civic values, supporting social inclusion or equity and fairness Protecting the environment and sustainability	Improvements in job creation and economic growth Protecting the environment and sustainability


Transactions
Transactions
Nonce :

Table A.4 (I): Citizens participation in the B4C use-cases

Citizens' participation	Use Cases					
	Weekend Fairs	Active Citizen	Land Titling	Energy Systems	Debt relief	e-vote for cell towers
How important is it to allow citizens to read the data?	High	High	High	Low	High	Medium
How important is it to allow citizens to write in the system?	Medium	High	Low	High	Not important	Medium
How important is the necessity of citizens to maintain a copy of the data?	High	High	High	Not important	Not important	Low

Table A.4 (II): Citizens participation in the B4C use-cases (end)

Citizens' participation	Use Cases						
	Digital Democracy	Claim verification 18+	Financial Emergency	Healthy	Stadjerpas	BlinG	BlinG
How important is it to allow citizens to read the data?	High	Not available	Low	Not	Not	High	Low
How important is it to allow citizens to write in the system?	High	Not available	Low	Not	Not	Low	Low
How important is the necessity of citizens to maintain a copy of the data?	Not available	Not available	Low	Not	Medium	Low	Not

Table A.5 (I): Technical characteristics of blockchain for cities use-cases

Technical Characteristics	Use Cases					
	Weekend Fairs	Active Citizen	Land Titling	Energy Systems	Debt relief	e-vote for cell towers
How important is the integration with legacy systems	High	High	High	High	High	High
How important is it to allow future integration with other systems	Medium	Medium	Medium	High	High	Medium
How important is security of the system	Medium	Medium	High	High	High	Medium
Framework used	Ethereum	Ethereum	Bitcoin	Ethereum	Sovrin	SAP
Current users in the system	100+ citizens	200+ citizens	Check	33 Households	5000	Not available
Public or private	Public	Public	Private	Public	Public	Private
Permissioned or permission less	Permissioned	Permissioned	Permissioned	Permissioned	Permissioned	Permissioned
Consensus mechanism	Proof of Authority	Proof of Authority	Similar to Practical Byzantine Fault Tolerance	Proof of Authority	Proof of Authority	Not available
Use of smart contracts	Yes	Yes	Yes	Yes	Yes	Yes
Use of cryptocurrency	Not available	Not available	No	No	No	Not available
Use of token	Not available	Not available	No	EWF Token	No	Not available
Type of cryptography	Public Key Cryptography, Hash Functions	Public Key Cryptography, Hash Functions	Hash Functions	Public Key Cryptography, Hash Functions	Public Key Cryptography, Zero Knowledge Proof	Not available

Table A.5 (II): Technical characteristics of blockchain for cities use-cases (end)

Technical Characteristics	Use Cases						
	Digital Democracy	Claim verification 18+	Financial Emergency	Healthy	Stadjerpas	BlinG	BlinG
How important is the integration with legacy systems	Not available	Not available	Low	Medium	High	Medium	Low
How important is it to allow future integration with other systems	Not available	Not available	Low	High	Low	Medium	Medium
How important is security of the system	High	High	High	High	High	High	High
Framework used	Hyperledger Sawtooth	Hyperledger Sawtooth	Hyperledger	Hyperledger	Unknown	Hyperledger IPFS	Hyperledger, Hyperledger Fabric
Current users in the system	60.000+	Not available	Not available	Not available	20000	Not available	Not available
Public or private	Public	Not available	Private	Private	Private	Private	Private
Permissioned or permission less	Permissioned	Not available	Permissioned	Permissioned	Permissioned	Permissioned	Permissioned
Consensus mechanism	None	Not available	Proof of Stake	Not available	Not available	Not available	RAFT
Use of smart contracts	YES	YES	No	YES	No	YES	YES
Use of cryptocurrency	No	No	No	No	Unknown at this stage	No	No
Use of token	No	No	No	No	Unknown at this stage	Not available	No
Type of cryptography	Zero Knowledge Proof, Attributes-based credentials	Zero Knowledge Proof, Attributes-based credentials	Public Key Cryptography, Zero Knowledge, Hash Functions	Zero Knowledge Proof	Unknown	Zero Knowledge Proof	Public Key Cryptography, Zero Knowledge, Hash Functions

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