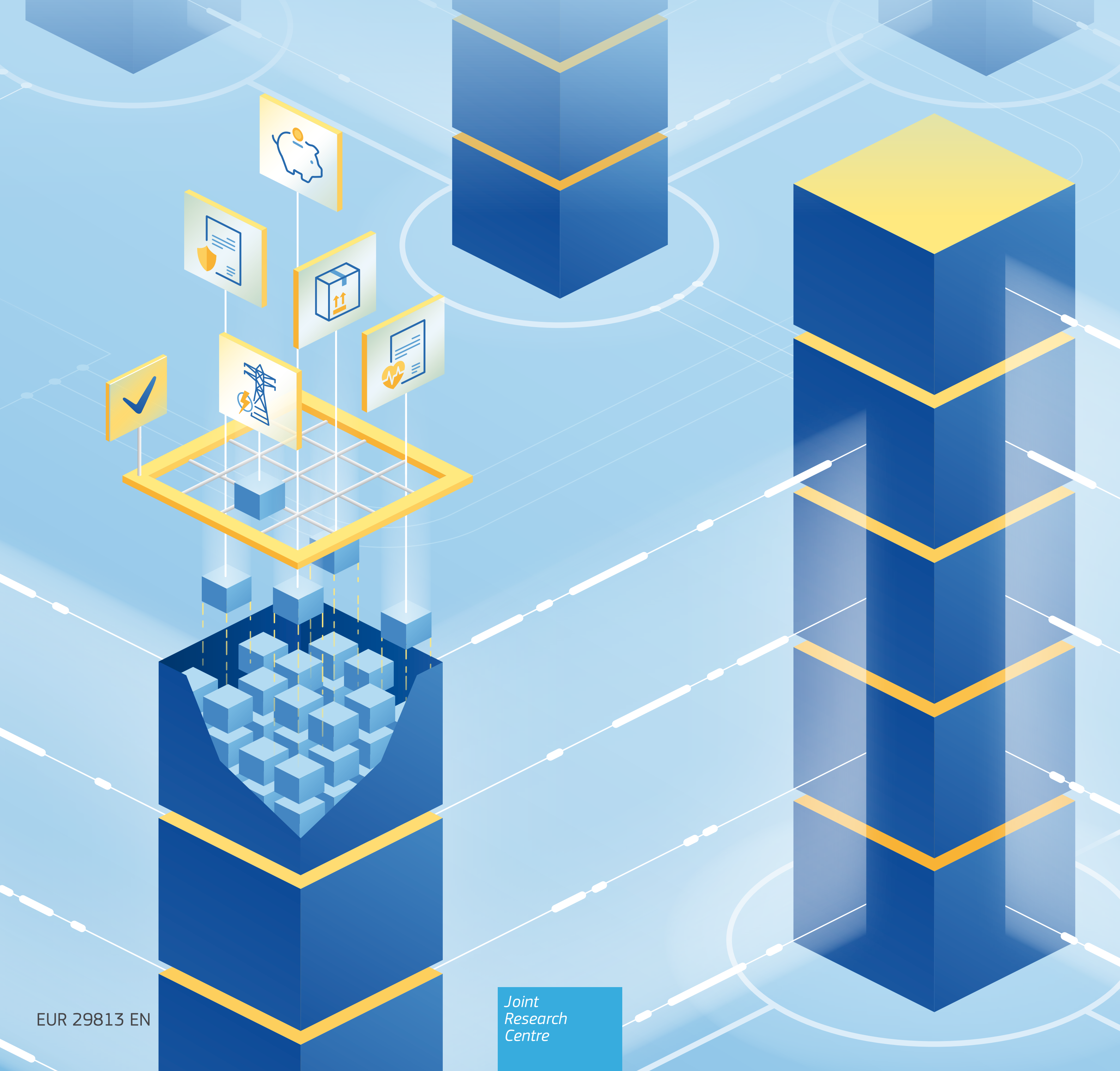
European Commission



# BLOCKCHAIN NOW AND TOMORROW

## ASSESSING MULTIDIMENSIONAL IMPACTS OF DISTRIBUTED LEDGER TECHNOLOGIES



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Joint Research Centre

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# EXECUTIVE SUMMARY

We have come a long way, in a short period of time, from the first views on Bitcoin and cryptocurrencies to a growing hype and media coverage capturing public attention, and now a profusion of funding and experimentation with blockchain or, in a broader sense, distributed ledger technologies.

Blockchain can enable parties with no particular trust in each other to exchange digital data on a peer-to-peer basis with fewer or no third parties or intermediaries. Data could correspond, for instance, to money, insurance policies, contracts, land titles, medical and educational records, birth and marriage certificates, buying and selling goods and services, or any transaction or asset that can be translated into a digital form. The potential of blockchain to engender wide-ranging changes in the economy, industry and society – both now and tomorrow – is currently being explored across sectors and by a variety of organisations.

The report *Blockchain Now and Tomorrow* brings together research from different units and disciplinary fields of the Joint Research Centre (JRC), the European Commission's science and knowledge service. It provides multidimensional insights into the state of blockchain technology by identifying ongoing and upcoming transformations in a range of sectors and setting out an anticipatory approach for further exploration. Moving beyond the hype and debunking some of its controversies, we aim to offer both an in-depth and practical understanding of blockchain and its possible applications.

## There is space beyond cryptocurrencies and financial applications

It is the technology behind cryptocurrencies – blockchain – that has been capturing most of the attention. Beyond its financial applications, its potential has come to the foreground in many other sectors, such as trade and supply chains, manufacturing, energy, creative industries, healthcare, and government, public and third sectors.

## A global ecosystem is on the rise from start-ups to capital investment

The rise of blockchain technology is witnessed by both the sharp growth in blockchain start-ups and by the volume of their funding. International players in the United States are taking the lead, followed by China and the European Union. Funding reached over EUR 7.4 billion in 2018 due to the explosion of ICOs and venture capital investments.

## Blockchain does not follow a 'one-size-fits-all' model

The potential opportunities and challenges of deploying blockchain technology are strongly related to context, application or sectorial issues. That is why organisations should not develop solutions looking for problems, but instead should find existing or foreseeable problems in their operations or business, and then look for possible blockchain solutions.

## Bottlenecks and complex challenges lie ahead

Blockchain technology is still at the embryonic stage and facing many challenges, such as performance and scalability, energy consumption, data privacy, integration with legacy infrastructures, or interoperability between different blockchains. Still based on a limited set of proven use cases, blockchain often entails additional risks and barriers for firms, businesses and organisations piloting it or interested in its deployment.

## The concepts of trust and disintermediation are changing

Despite widespread misconceptions, blockchain does not imply the total elimination of intermediaries or third parties. Some intermediaries may disappear but new ones will appear and traditional ones, like governments, will continue to play a long-term role, not least to guarantee equal conditions for participation, check the quality and validity of data, decide on responsibility and liability, or settle disputes and enforce rules.

## Regulatory frameworks and guidelines are catching up

Policymakers and regulators need to progress in assessing whether existing policies and laws are fit for purpose or if new frameworks will be required. Pressing discussions include, for instance, the legal classification of tokens and coins, validity of smart contracts, applicable jurisdictions, consumer and investor protection, enforcement of anti-money laundering requirements, and data protection and privacy safeguards.

## Integration with digitisation initiatives and programmes is key

Blockchains will be complementary or will work together with other key digital technologies, such as artificial intelligence, internet of things, data analytics, cloud computing, robotics and additive manufacturing. The development of blockchain should be connected to existing digitisation initiatives and programmes to avoid overlaps and to maximise impact.

## Piloting and experimentation spaces are needed

As an emerging technology, blockchain requires the multiplication of use cases to test its added value in specific applications and sectors. Further support and funding for frontier pilots and experimentation spaces must bring together a diversity of stakeholders from universities, research centres, industry, SMEs and start-ups.

## Capacity building and knowledge sharing can be decisive

Environments such as regulatory sandboxes and other experimentation spaces can promote more direct exchanges between policymakers, regulators and supervisors, on the one hand, and blockchain companies, start-ups and entrepreneurs, on the other. Key benefits can include testing new solutions and business models and improving the quality and speed of policy guidance.

## Blockchain calls for an interdisciplinary and comprehensive approach

Blockchain applications can have far-reaching implications at policy, economic, social, technical, legal or environmental level. Potential changes, for example, in economic and business models, governance mechanisms or trust between parties, can only be grasped through a mix of different areas of knowledge, including computer science, economics, law, public finance, environmental sciences, and social and political sciences.

## Monitoring should be combined with an anticipatory outlook

Policy dilemmas today involve a balance between adequate enforcement of existing regulations from day one, and the flexibility to accommodate an evolving technology with both foreseeable and unforeseeable benefits. This balance can be grounded in a foresight and trend monitoring approach to enable preparedness and adaptation to an increasingly rapid pace of change.

# INTRODUCTION

## Blockchain and distributed ledger technologies (DLTs) can bring many opportunities…

In our increasingly interconnected world, a vast set of opportunities can emerge from blockchain as a technology that could enable parties with no particular trust in each other to exchange any kind of digital assets (money, contracts, land titles, medical and educational records, services or goods) on a peer-to-peer basis with fewer to no intermediaries.

As a tamper-resistant and time-stamped database, blockchain technology can allow individuals, firms, public organisations and other entities to validate transactions and update records in a synchronised, transparent and decentralised way. These new mechanisms for creating and managing data can be impactful across sectors – for instance, when it comes to increasing efficiency and automating processes, reducing costs, or spurring new organisational and business models. Possible benefits of transparency, security and increased trust are now apparent for a range of applications and use cases where it is key to move from siloed to more open systems.

## …and many challenges

Blockchain's potential for a myriad of sectors has increasingly come to the foreground, even though it is still in an embryonic form as an emerging or early-stage technology. Core technical bottlenecks remain unresolved which, depending on the type of blockchain, can include scalability and performance, interoperability, high energy consumption, and the protection of personal, sensitive or confidential data. Regulatory uncertainties over the formal status of blockchain applications are also causing extra ambiguity and risk for firms and other organisations either piloting blockchain or interested in its deployment.

Currently, many of blockchain's potential benefits remain unfulfilled or have yet to be fully tested. Its development faces questions over possible impact, added value or concrete directions for widespread adoption. And a fast-paced, uncertain but, at the same time, highly promising field calls for further research and experimentation bringing together policy, economic, social, technological, legal and environmental dimensions.

## Why this report?

In recent years, we have witnessed an outburst of interest around blockchain. Some say it will bring nothing short of a revolution which will deeply disrupt the way we exchange data and create value in an increasingly digital world. Others dismiss it as an over-hyped and obscure technology with no real or concrete implementations compared to other existing technologies or alternative emerging solutions.

This report aims not only to debunk current misunderstandings and magnified promises around blockchain, but also to provide an independent view on the challenges and opportunities for its development and uptake within the European context.

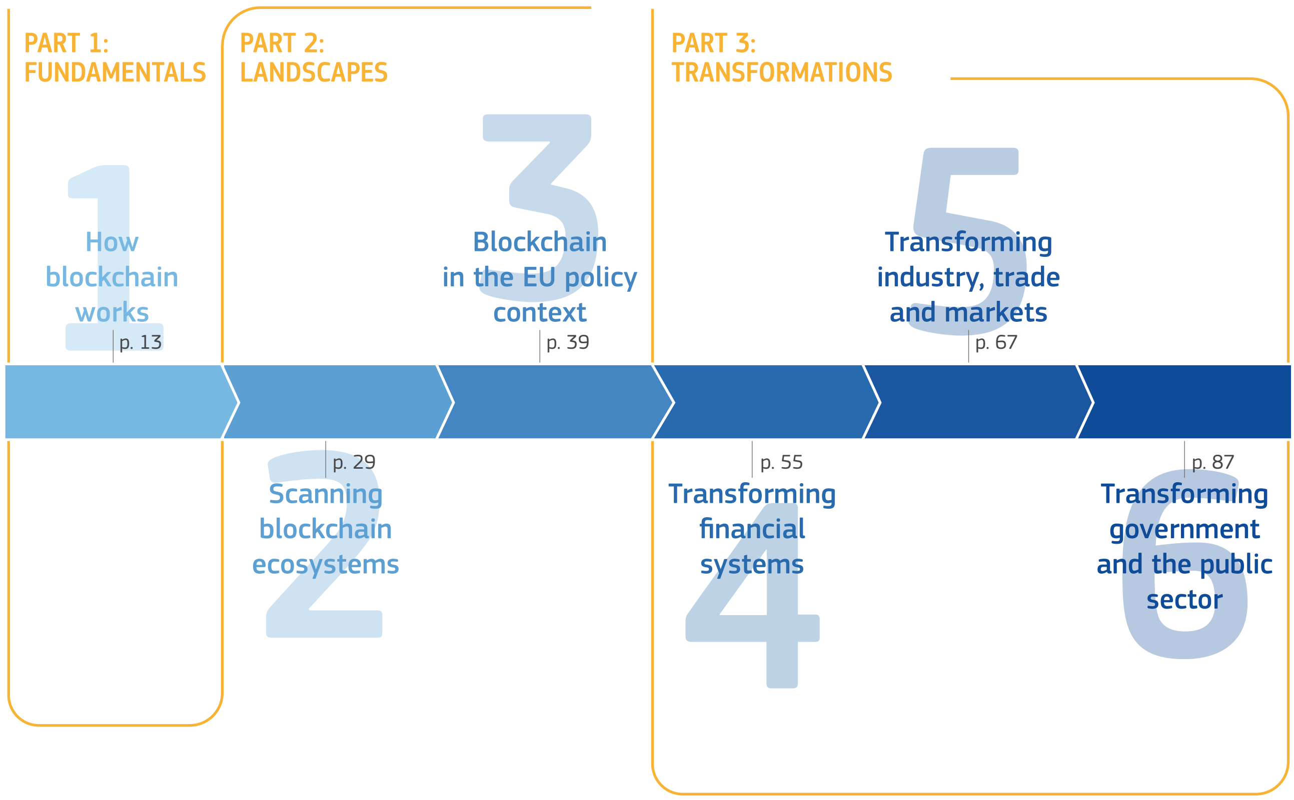
It is important to understand that blockchain technology is not the same as crypto-currencies, which is only one type of application with its own set of controversies. It is also important to recognise that blockchain is not limited to its financial applications that are usually at the core of discussions focused, for instance, on trading bubbles or initial coin offerings (ICOs). Instead, amid unfolding developments and uncertain futures, blockchain has potential applications in many other sectors, from advanced manufacturing or health to education and public and third-sector engagements with citizens.

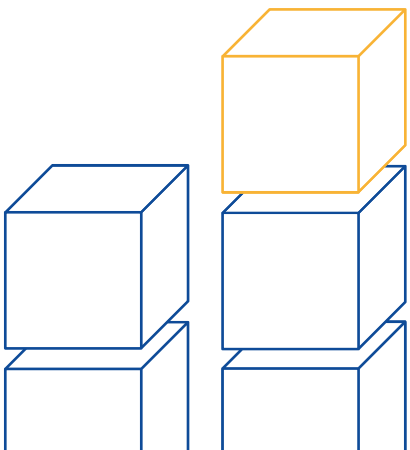
In recent years, as the science and knowledge management service of the European Commission (EC), the Joint Research Centre (JRC) has developed multidisciplinary research that underpins this report. Through its work, the JRC aims to support the EC and policymakers to prepare for and foresee major transformations that are arising or may arise from the adoption of blockchain technology.

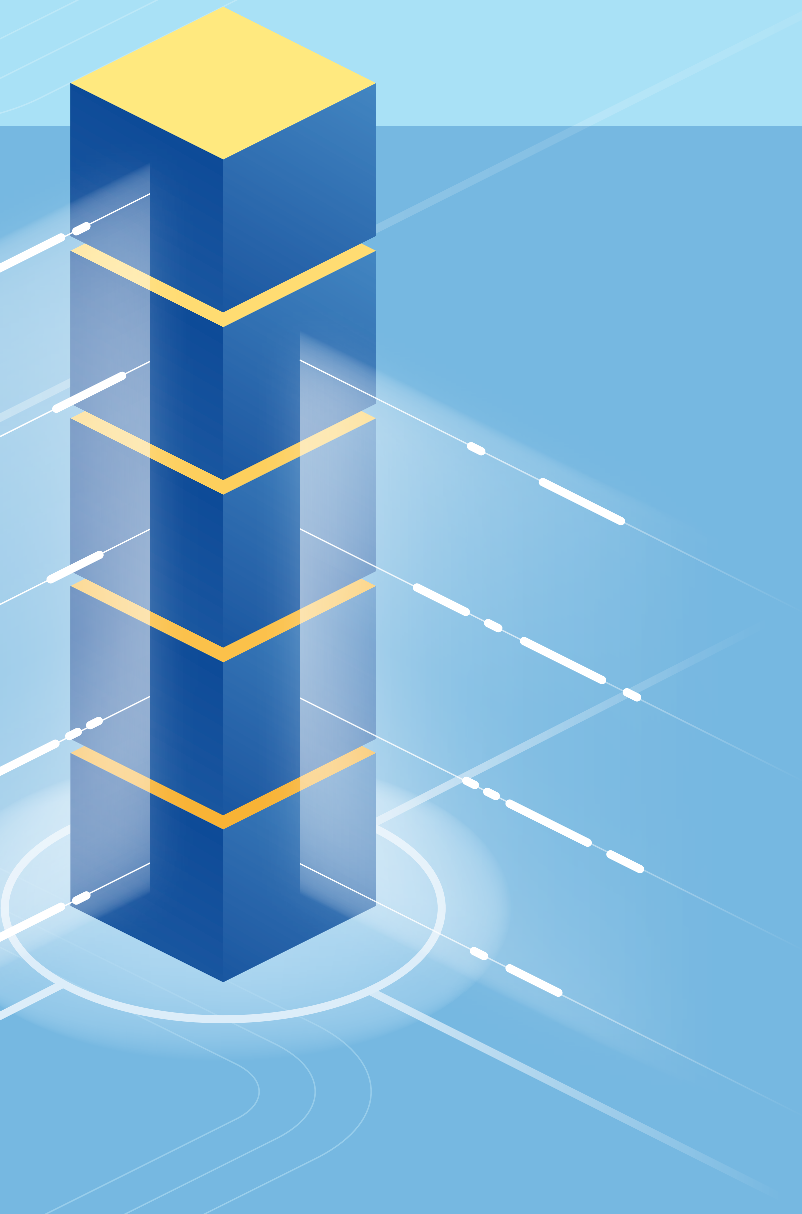
## Quick guide

The report is divided in three parts: Fundamentals, Landscapes and Transformations. In *Part I – Fundamentals, Chapter 1* starts with an overview of how blockchain technology works in order to better understand its possibilities and limitations.

In *Part II – Landscapes, Chapter 2* discusses the potential impact of this emerging technology, based on European and global trends among blockchain start-ups in terms of numbers, profiles and funding. This is followed by an outline of key initiatives and activities at EU policy level in *Chapter 3,* which showcases how European institutions are looking into the growth and potential of blockchain. In *Part III – Transformations, Chapters 4, 5* and *6* give a more in-depth account of the opportunities and challenges in different sectors with both ongoing and possible use cases. Finally, *Chapter 7* concludes the report by providing a summary of key insights from previous chapters and paths ahead for reflection.





# PART 1: FUNDAMENTALS


## SUMMARY

As a tamper-resistant and time-stamped database, blockchain technology can allow individuals, firms, public organisations and other entities to validate transactions and update records in a synchronised, transparent and decentralised way. Instead of relying on intermediaries or third parties, trust between parties is based on the rules or consensus mechanisms everyone follows to verify, validate and add transactions to the blockchain. However, rather than just one 'blockchain', there are many different 'blockchains' with distinct functionalities and architectures. Despite their rapid development in recent years, blockchain systems still face a series of challenges, including performance and scalability, energy consumption, integration with legacy infrastructures, interoperability, potential collusion between participants, management of public/private keys, and the protection of personal, sensitive or confidential data.

# HOW BLOCKCHAIN WORKS

## 1.1. What is a blockchain?

**Blockchain and other distributed ledger technologies (DLTs) are technologies enabling parties with no particular trust in each other to exchange any type of digital data on a peer-to-peer basis with fewer or no third parties or intermediaries.** Data could represent, for instance, money, insurance policies, contracts, land titles, medical records, birth and marriage certificates, buying and selling goods and services or any other type of transaction or asset that can be translated into a digital form.

To be clear on the terminology, blockchain is part of the broader family of DLTs. DLTs are particular types of databases in which data is recorded, shared and synchronised across a distributed network of computers or participants. Blockchain technology is a subset of DLTs employing cryptographic techniques to record and synchronise data in 'chains of blocks'. The difference concerns the way data is distributed, verified and registered (the difference between public/private and permissionless/permissioned is given below). In short, all types of blockchain are DLTs but not all DLTs are blockchains. For the sake of simplicity, this report will mainly use the terms blockchain or blockchains, and will distinguish between DLTs where necessary.

**Blockchain is a database (ledger) operating in a distributed network of multiple nodes or computers that keeps track of data transactions** (Wright and De Filippi, 2015). It is so called because of the particular way transactions are recorded and verified between parties *(Figure 1)*. A transaction with party B is requested by party A, such as the transfer of money, setting up a contract, or sharing records. This transaction is broadcast to a distributed network of nodes or computers which will validate it according to an agreed set of rules (a 'consensus' mechanism). When validated, this transaction will be bundled with others into a new 'block' and added to the blockchain.

> A blockchain is run through a distributed network of participants who do not necessarily trust each other but follow the same rules (consensus).

The whole process ensures that each block is created in a way that irrefutably links it to the previous one and 'the next one, thereby forming a chain of blocks or blockchain. The unique record that forms a blockchain is shared by each node or computer in the network and is constantly updated and synchronised. As a database or ledger, ultimately a blockchain stores the records of all transactions ever executed across a network.

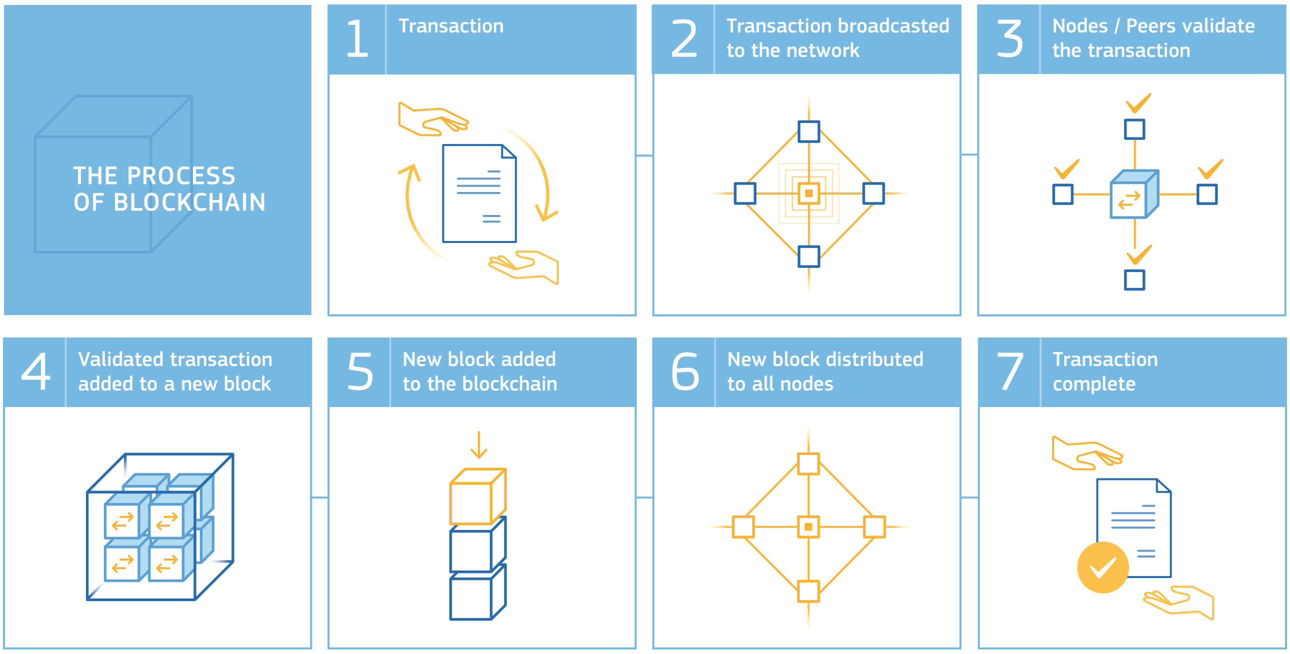



**Figure 1:** How a blockchain works

There are many different blockchains with distinct functionalities and architectures. They can be distinguished depending on who can read, execute and validate transactions.

**When anyone can read and access a blockchain it is categorised as 'public' or 'open'** which means that anyone can access a whole blockchain and read its contents. **When only authorised entities have access, a blockchain is considered 'closed' or 'private'** *(Figure 2).*

Blockchains can be further categorised as 'permissionless' or 'permissioned' depending on who can send transactions and who can validate them. **If anyone can send and validate transactions, the blockchain is called permissionless. If entities need to be authorised to execute or validate transactions, or both, the blockchain is called permissioned** *(Figure 2).* At this point in their ongoing technical development, hybrid blockchains combining different aspects along a continuum are also available (Peters and Panayi, 2016; Danezis and Meiklejohn, 2015).

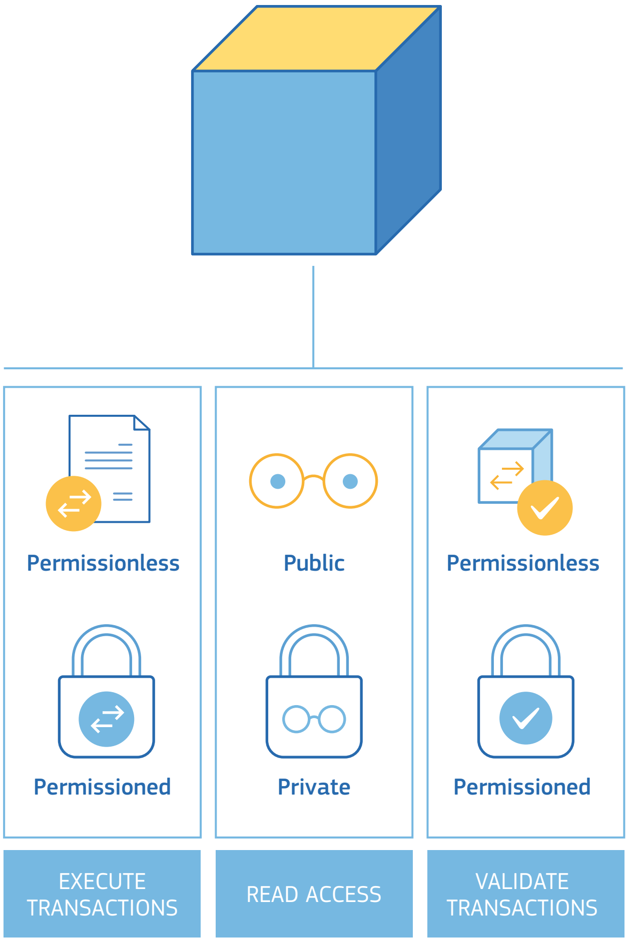



**Figure 2:** Blockchain attributes

In general, four major blockchain types can be distinguished: public permissionless, public permissioned, private permissioned and private permissionless blockchains *(see overview in Table 1).* The yellow dots are the validating nodes, which means they are able to validate the transactions in the system and participate in the consensus mechanism. The light-blue dots are participants in the network in the sense that they can transact but are not able to participate in the validation mechanism. The light-blue dots do not participate in the consensus mechanism. A blue circle means that only the nodes within the circle can see the transaction history. Illustrations without a circle mean that everyone with an internet connection can see the blockchain's transaction history.

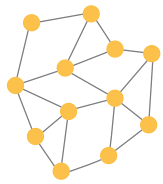
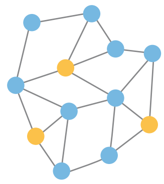
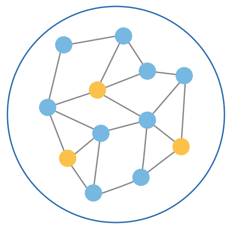
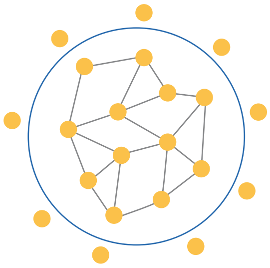
| Blockchain type | Explanation | Example | Visualisation |
|---|---|---|---|
| **Public permissionless blockchains** | In these blockchain systems, everyone can participate in the blockchain's consensus mechanism. Also, everyone worldwide with an internet connection can transact and see the full transaction log. | Bitcoin, Litecoin, Ethereum |  |
| **Public permissioned blockchains** | These blockchain systems allow everyone with an internet connection to transact and see the blockchain's transaction log, although only a restricted number of nodes can participate in the consensus mechanism. | Ripple, private versions of Ethereum |  |
| **Private permissioned blockchains** | These blockchain systems restrict both the ability to transact and view the transaction log to only the participating nodes in the system, and the architect or owner of the blockchain system is able to determine who can participate in the blockchain system and which nodes can participate in the consensus mechanism. | Rubix, Hyperledger |  |
| **Private permissionless blockchains** | These blockchain systems are restricted in who can transact and see the transaction log, although the consensus mechanism is open to anyone. | (Partially) Exonum |  |

**Table 1:** Examples of blockchain types

## 1.2. Features and challenges

The potential of blockchain is based on a particular combination of key features (Tasca and Tessone, 2018; Rauchs et al., 2018) and associated challenges, as explained below.

### 1.2.1 Decentralisation

**A blockchain is run through a distributed network of participants who do not necessarily trust each other.** As a result, blockchains take (at least in part) the place of other intermediaries or trusted third parties on whom transactions usually rely. Instead, trust between participants is based on the **set of rules that everyone follows to verify, validate and add transactions to the blockchain** – a consensus mechanism. The best-known consensus mechanism is 'proof of work' (PoW) which relies on the computational or processing power of the nodes or computers (called 'miners') to solve a complex mathematical puzzle as quickly as possible (see *section 1.3.4* for more details).

The fact that there is no central entity controlling the system creates a strong resilience for blockchains. **There is no central point of failure** and, in addition, the system is very difficult to attack. The existence of multiple and distributed nodes makes it very difficult to target the majority simultaneously, or to completely break down the whole network.

However, blockchains currently have **limitations regarding scalability and performance.** Public and permissionless blockchains, like Bitcoin or Ethereum, can only handle a limited number of transactions. However, other off-chain solutions, such as Lightning for Bitcoin[1] and Raiden for Ethereum[2], are trying to address this scalability issue. The PoW process also means high energy consumption, although there is no consensus, for instance, over Bitcoin's actual electricity consumption (Mccook, 2018; Mora et al., 2018; *New York Times,* 2018). Alternative consensus mechanisms, such as 'proof of stake', are under development and might prove to be less energy intensive *(see section 1.3.4).*

Recent research has also debunked this feature of decentralisation. Evidence of the high concentration or dependency of mining among a limited number of participants (Gencer et al., 2018), or large-scale mining activity pools (Caccioli et al., 2016; Rauchs et al., 2018) suggest that few if any blockchain systems are actually decentralised. For example, the situations mentioned can allow for potential collusions or attacks from a group of participants controlling a majority of computational resources ('51 % attack').

Concerns over centralisation also arise in private and permissioned blockchains such as Ripple or Hyperledger. In these systems, a group of participants, companies or administrators preselects or gives access to participants. This can be considered to be a centralised or semi-centralised model, in which a set of participants retain significant control that can lead to arbitrary decisions and high costs, as is happening today in other non-blockchain systems (Crespigny, 2018).

### 1.2.2 Tamper-resistant

Another important feature of blockchains is that it is extremely difficult to change or delete the record of transactions (only possibly through a '51 % attack' or by a consensus of the network participants). Every modification in the blockchain is visible to everyone, so it is almost impossible to make changes without someone noticing them. Public-private keys or cryptographic signatures also ensure the integrity and authentication of transactions.

In this sense, **records in a blockchain are tamper-resistant.** The characteristics of non-repudiation and non-forgeability guarantee there is a unique and historical version of the records which can be agreed and shared among all participants in a particular network (or chain).

One of the most discussed issues concerns potential conflicts between a blockchain and the EU General Data Protection Regulation (GDPR) right to data erasure, best known as 'the right to be forgotten' (Finck, 2018). The potential need to identify and contact all the necessary nodes with a request to delete or even rectify data ('right to amendment') might not be feasible in reality. Also, any changes in a tamper-resistant database may erode the participants' trust in the blockchain itself and lend it to suspicions of tampering and interference.

It is important to note that tamper-resistant is not the same as 'immutable' or 'unchangeable'. Despite its decentralised nature, this technology is still vulnerable to threats and attacks, which may hypothetically allow individuals or groups to change the records or reverse transactions. Furthermore, depending on the consensus mechanism in place, participants in a blockchain can in fact vote or choose to make changes or alter the record (Coindesk, 2016; Quartz, 2016). This means that **tamper-resistant should not be understood as unchangeable, but rather as hard to change** (Walch, 2017).

> Tamper-resistant is not the same as 'immutable' or 'unchangeable', *but rather means extremely difficult or hard to change.*

Changing the record of transactions or simply a blockchain via consensus has happened before. One of the most controversial cases was 'the DAO hack' in which the theft of funds was restored through a community decision to split or 'fork' the underlying record. This case generated wide debate as to what trust means in blockchain systems. It laid bare the importance of governance because, in the end, blockchains still rely on a set of agents (developers, miners, users and other participants) who have specific roles and can intervene in specific moments when it is perceived (or required by law) to fix problems, upgrade the system or reverse unintended consequences.

### 1.2.3 Transparency

The ledger or blockchain is accessible to all participants or to a predefined set of participants. While in private or closed blockchains access to the records can be restricted to certain participants, in public or open blockchains everyone with an internet connection to the network has the same rights to access and/or update the ledger according to the consensus mechanism in place. Thus, in this last case, **all transactions are transparent and visible, which may increase auditability and trust in the network.**

Yet transparent data in a public blockchain might be a problem when certain information is not meant to be publicly available, or has to be altered later due to errors, inaccuracies or other problems in data entry (Finck, 2017; Hogan Lovells, 2017). This is currently one of the most disputed issues – a still unsolved trade-off between transparency and privacy in public or open blockchains.

A possible solution is to store confidential, sensitive or personal data 'off-chain' or in other databases. This might also be an option to store larger sets of data taking into account, for instance, the space limitations of most blockchains. This data would be linked to the blockchain through a hash reference or pointer, keeping access to the original data in the other database restricted to authorised parties, or using a blockchain platform with a built-in off-chain decentralised database (see for example the EFTG project in *section 3.4*). Another option is to use a hybrid or private blockchain which currently offer more flexibility to configure different levels of access to personal, sensitive or private information in a case-by-case logic.

> "Transactions are transparent and visible to all participants *or to a predefined set of participants which may increase auditability and trust.*"

Moreover, **cryptographic protocols offer pseudonymisation, not complete anonymisation** (Van Wirdum, 2015). Using Bitcoin as the example, on the one hand, transactions are not tied to real identities (anyone can transfer Bitcoin to others through private keys with no personal information) and are randomly transmitted over the peer-to-peer network. However, on the other hand, transactions can still be de-anonymised through a number of different techniques, which may lead to the re-identification of specific data subjects in indirect and remote cases (Goldfeder et al., 2017; Coincenter, 2015).

Ongoing experiments and research are trying to tackle such concerns by using cryptographic protocols like 'zero-knowledge proofs', which may add additional layers of encryption and/or obfuscation in order to conceal details about transactions. If properly designed according to the needs of organisations, blockchain systems could potentially even enable decentralised and privacy-friendly solutions.

### 1.2.4 Security

Keeping track and verifying information in a secure way is one of the key advantages of a blockchain. **All transactions are time-stamped,** that is, data such as details about a payment, a contract, transfer of ownership, etc., is linked publicly to a certain date and time. This means that no one should be able to modify what has been recorded and time-stamped. This makes it particularly useful for different parties to check when and who made a specific transaction, or to certify that data existed at a given moment in time.

Furthermore, blockchain relies on **public-private key cryptography to ensure the authenticity and integrity of data exchanges or transactions.** Participants have a distinct identity based on a combination of public and private keys: public keys are widely shared with the others in the network, while private keys are kept secret. For instance, messages or transactions encrypted with a private key can only be opened by recipients with the corresponding public key (shared by the sender). Or, if a message is encrypted with a public key, it can only be decrypted by a specified recipient using her or his private key.

However, a major source of security vulnerability lies in key management (ENISA, 2016).
The responsibility and burden for participants to manage their public and private keys can be as simple and serious as losing a phone or a back-up of their credentials (Wired, 2017a; Wired, 2017b). Many people rely on third parties, such as mining companies or digital wallet services, to manage

their keys, which ultimately reintroduces operational security risks if these companies are hacked (Fortune, 2017c).

No one has yet managed to break the cryptography and decentralised architecture of public blockchains, although some say this might happen with quantum computing (Forbes, 2017).

Quantum-information-based technologies are foreseen as a digital revolution due to the impressive computing power envisaged for quantum computers. Solutions to 'unsolvable problems' might be easy to find. Unfortunately, such problems are sometimes at the root of system security which, for example, is the case for some cryptographic algorithms used as blockchains' building blocks. The time when quantum computing will be powerful enough to threaten the security of blockchain has yet to arrive. In fact, there is no clear consensus about when this might happen. The JRC survey on quantum technology (Lewis et al., 2018) gives a median estimate of 15 years plus/minus 11.5 years.

> "Smart contracts are neither 'smart' (capable of translating complex legal agreements) *nor 'contracts' (no underlying legal provisions).*"

Consequently, the blockchain community needs to be proactive by already preparing for the next generation which must be quantum resistant. Obviously, the advent of quantum computing will not only affect blockchain but all the systems relying on weakened cryptographic algorithms. Therefore, a new generation of cryptosystems – generally called post-quantum cryptographic algorithms – has been developed and can be helpful for the new generation of quantum-resistant ledgers. Similarly, advantages of other advances in new quantum technologies (such as quantum key distribution protocols) should not be ignored as this could also help to increase the security of blockchain systems, for example by improving the security of network communications.

### 1.2.5 Smart contracts

Blockchain technology can be used to implement other decentralised services besides currency transactions where trust is inbuilt based on blockchain intrinsic properties. One of the main reasons is the extra features that can be incorporated on top of blockchain, one of the most important of which is probably the use of smart contracts.

**Smart contracts are computer programs that are capable of carrying out the terms of agreement between parties without the need for human coordination or intervention** (Szabo, 1997; Buterin, 2015). These agreements can be recorded and validated into a blockchain which can then automatically execute and enforce the contract usually under 'if-then' instructions: 'if' something happens (for example, if you rent and pay for a car and short-term insurance) 'then' certain transactions or actions are carried out (the car door unlocks and the payment is transferred). A smart contract enables two or more parties to perform a trusted transaction without the need for intermediaries. The way in which transactions are verified and added on the blockchain guarantees that conflicts or inaccuracies are reconciled, and that in the end there is only one valid transaction (no double entries).

Smart contracts became popular with Ethereum which uses the open source Ethereum Virtual Machine (EVM) blockchain-based distributed computing platform. The main goal of the EVM is to keep a distributed record of transactions performed using the Ethereum digital currency, Ether (ETH). Other platforms are now also offering smart contract functionalities, such as Hyperledger's umbrella projects. The basic principles remain the same, even if in some cases implementation and the way smart contracts are handled differ.

Some argue, however, that this is actually a misnomer in the sense that smart contracts are neither 'smart' (capable of translating complex legal agreements into software) nor 'contracts' (they have no underlying legal or contractual provisions) (Orcutt, 2018). In addition, smart contracts are currently only feasible or applicable under limited and strictly circumscribed conditions – for instance, when there is no need for dispute resolution, or when there is a reliable oracle providing accurate information. Relevant challenges may arise when looking at the possibilities for people and organisations to create their own systems of rules or smart contracts as a type of automated private regulatory frameworks or *lex cryptographica,* which may avoid jurisdictional rules and operate transnationally in the near future (De Filippi and Hassan, 2016; De Filippi and Wright, 2018; Quintais et al., 2019).

## 1.3. Looking into blockchain implementation: Bitcoin

Since it all started with Bitcoin and most of the current blockchain technology relies on Bitcoin principles, it is important to explain how blockchain and DLTs work by mentioning how Bitcoin works. The basic Bitcoin principles and key terms described below are used in almost all current blockchain implementations.

Bitcoin is a cryptocurrency system created in 2009 by Satoshi Nakamoto (2008), a pseudonym of the person or group of people who designed and implemented the system[3]. The term Bitcoin, with a capital B, refers to the system, while bitcoin indicates the coins generated and spent inside the system. Bitcoin was the first cryptocurrency created and, following its implementation, there are now more than 2 000 different cryptocurrencies (as of February 2019) based on most of its founding principles[4].

**Bitcoin is a digital currency: all coins are created, spent and transferred digitally inside Bitcoin's ecosystem.** What makes it special is that **there is no central entity creating coins and verifying transactions.** Instead, the entities or users who are part of the Bitcoin network take on this role.

In the Bitcoin system, users are represented by addresses. An address can be regarded as being similar to a bank account number. However, one importance difference in Bitcoin is that the account holder cannot be identified, at least not in a straightforward way. An example of a Bitcoin address is 3PtFPuXZxS1CBHdG2E5EeU6FcFqGGmzepF. In this way, Bitcoin accounts are pseudonymous. Addresses are created using public key cryptography.

Without going into details, the owner of the address is the holder of the private key that corresponds to the public key that has been used to create the address. Therefore, the private key is the proof that a specific address belongs to this user. As a result, private keys must be protected as their loss means loss of proof that this address belongs to the user and, as a direct consequence, the inability to use the bitcoins in the corresponding accounts. It is important to point out that as Bitcoin is not controlled by an entity, it is impossible to claim missing private keys. It is the responsibility of each holder to keep her or his private keys secure.

Addresses are used to hold bitcoins; a user is usually the holder of many addresses. There is no limit on how many addresses a user can have – in fact, it is advised to use a new address when receiving bitcoins rather than reusing addresses. This makes the tracking of addresses and linking them to the owners more difficult.

To perform a transaction – for example, Alice wants to sends 20 bitcoins (BTC) to Bob – Alice will have to prove that she is the owner of an account, or a number of accounts, that hold at least 20 BTCs. She does this by digitally signing the transaction with the private keys of these accounts.

Once signed, rather than being sent directly to Bob, the transaction is broadcast on the whole Bitcoin network. Alice's transaction is pending until a special entity in Bitcoin, known as a 'miner', verifies it. The miners collect pending transactions then confirm their correctness before verifying them. To summarise, Alice wants to send 20 BTC to Bob *(Figure 3)*. The closest sum of her addresses to the targeted amount is 21.01 BTC. The transaction is broadcast on the Bitcoin network and, once verified, Bob receives the 20 BTC, the miner receives 0.01 BTC as a transaction fee and 1 BTC is returned to Alice as change.

**Once the transactions have been verified they are stored in a tamper-resistant and shared data structure comprising a list of blocks which are chained together, known as a blockchain.** New transactions are inserted into a block at the end of the chain and linked to the previous block of transactions, as each block references the previous block's hash *(see section 1.3.2.)*. The chain continues backwards until reaching the first block of the blockchain which is called the 'genesis block'. As a whole, **a blockchain contains a ledger of all the transactions that have taken place in the history of the currency, which is saved by all participating nodes and distributed across the entire network.** *Figure 4* shows a blockchain and the ledger it contains.

The verification of a transaction involves two main tasks. The first one is to ensure that Alice has the number of BTCs she claims in her addresses. This is verified by going backwards in history and cross-checking how Alice received these BTCs. This verification will show, for example, that Alice

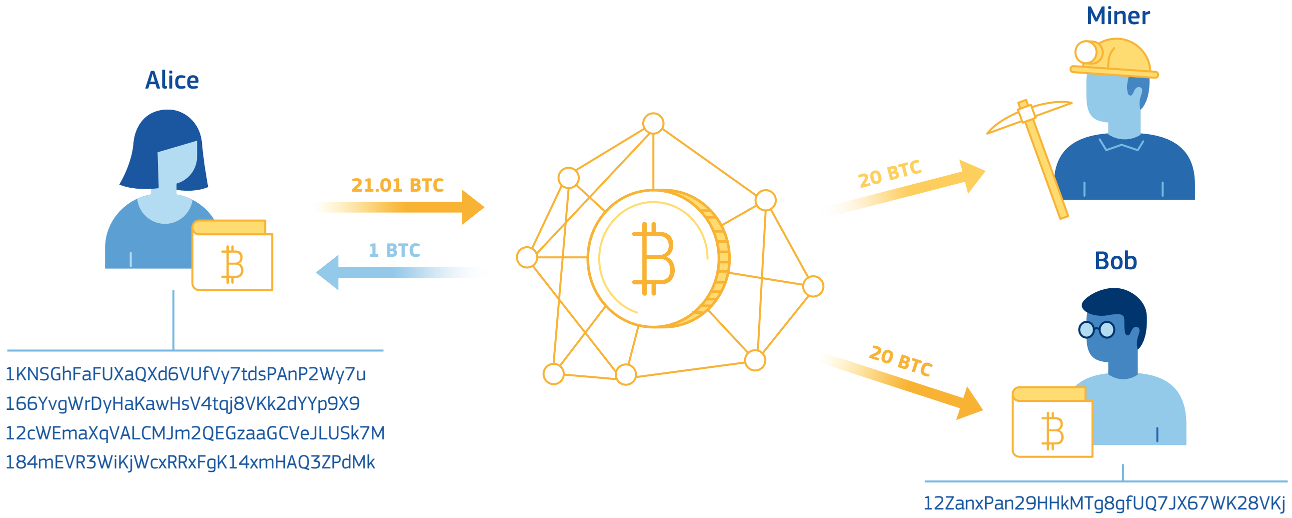
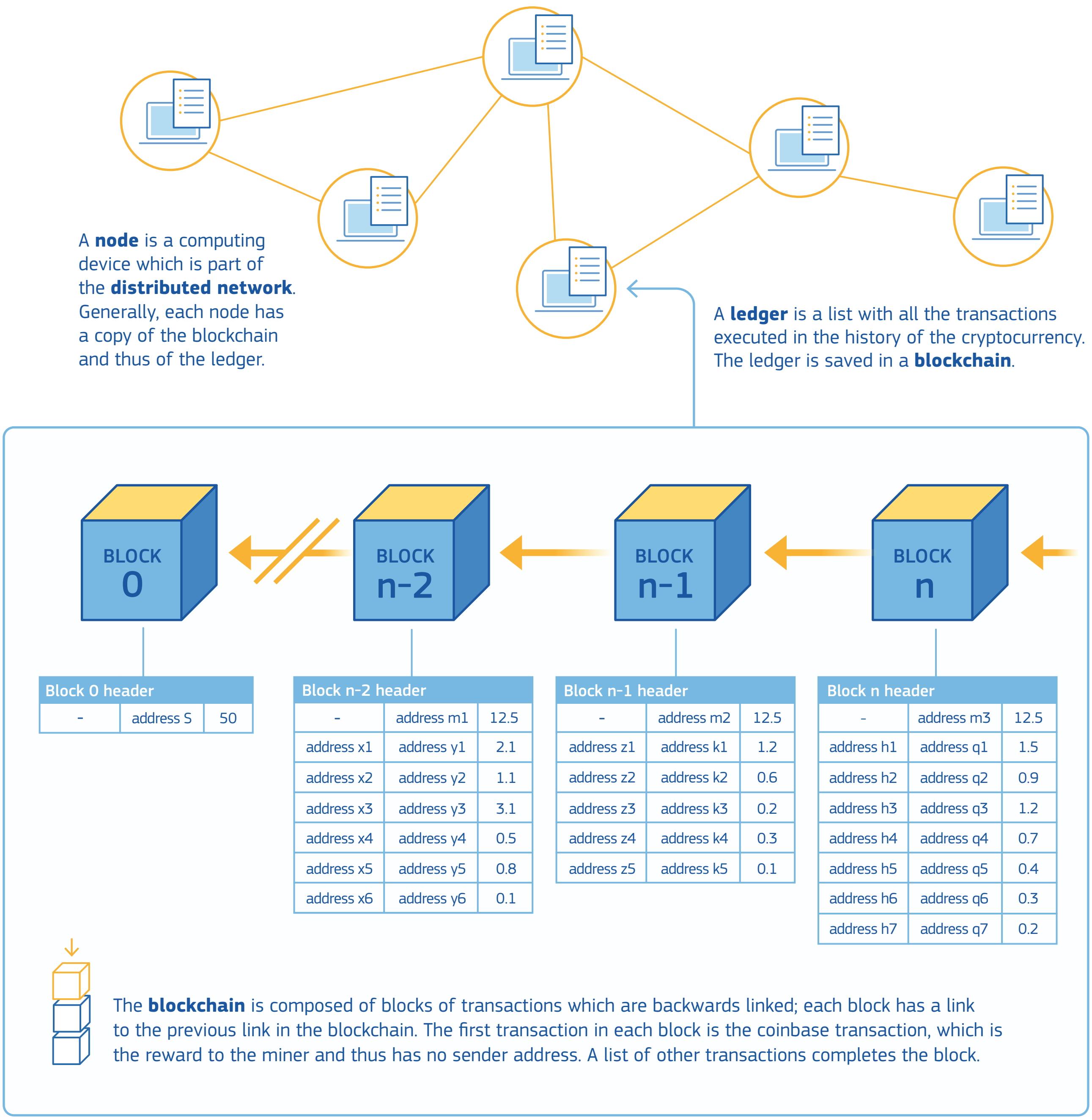



**Figure 3:** A Bitcoin transaction




| Block 0 header | | |
|---|---|---|
| - | address S | 50 |

| Block n-2 header | | |
|---|---|---|
| - | address m1 | 12.5 |
| address x1 | address y1 | 2.1 |
| address x2 | address y2 | 1.1 |
| address x3 | address y3 | 3.1 |
| address x4 | address y4 | 0.5 |
| address x5 | address y5 | 0.8 |
| address x6 | address y6 | 0.1 |

| Block n-1 header | | |
|---|---|---|
| - | address m2 | 12.5 |
| address z1 | address k1 | 1.2 |
| address z2 | address k2 | 0.6 |
| address z3 | address k3 | 0.2 |
| address z4 | address k4 | 0.3 |
| address z5 | address k5 | 0.1 |

| Block n header | | |
|---|---|---|
| - | address m3 | 12.5 |
| address h1 | address q1 | 1.5 |
| address h2 | address q2 | 0.9 |
| address h3 | address q3 | 1.2 |
| address h4 | address q4 | 0.7 |
| address h5 | address q5 | 0.4 |
| address h6 | address q6 | 0.3 |
| address h7 | address q7 | 0.2 |

Figure 4: Blockchain and the ledger

received one from Carl and that Carl received this BTC from David, and so on. The verification will go backwards until the process reaches an address that has not received BTCs from anyone; they were simply assigned to this address. This is the address of a special entity in Bitcoin known as a 'miner' – the BTCs have been given to him as a reward for her or his work in verifying transactions. It is important to clarify that the BTCs given as a reward did not previously belong to someone else. They are created for this purpose and are given directly to the miner, who becomes their first owner. The transaction by which the miner received the reward is called a coinbase transaction; this is how new BTCs enter into circulation. So, as soon as the verification of Alice's coins reaches the coinbase transaction, then the path that was followed can be verified and trusted, and Alice's claim of holding a specific number of BTCs in her addresses is considered true. The second task to be validated in the transaction is that Alice does not send the same transaction twice – for example, she does not send the same transaction to Bob and Chuck at the same time. This is verified through the blockchain. When Alice sends a transaction to Bob it is stored in the blockchain. If she tries to send the same transaction to another person the transaction will fail as the first transaction is already in the blockchain so, as previously explained, verification of the transaction by the miners will not go through.

### 1.3.1 Wallets

As previously mentioned, **each user owns many Bitcoin addresses.** To facilitate the use of multiple addresses and remove the burden of handling a large number of encryption keys, specialised software called a 'wallet' is used. **The wallet handles all the user's addresses, and thus all the corresponding keys, and automatically combines accounts in order to perform transactions.** Usually, when making a transaction, it is highly improbable that an existing address holds the exact number the user wants to transfer. In this case, the wallet will gather the amount from multiple addresses, create a transaction for them and perform the transaction without bothering the user with all the details.

The wallet usually 'sits' on top of the client interface in the network, called a node. This entity connects to the Bitcoin network thereby becoming a Bitcoin peer. There are two main types of wallets based on the kind of node they use: the 'full wallet' and the 'light wallet'.

The full wallet is a complete node in the sense that when it connects to the Bitcoin network it downloads and verifies the complete blockchain locally. Then, during its operation, it continues to download new blocks and maintain the latest blockchain version.

The light wallet, as its name suggests, is usually used in systems with less computational and storage capacity, such as mobile devices. The node it relies on does not download the whole blockchain but relies on a set of predefined trusted peers in order to view the latest blockchain state.

### 1.3.2 Hashing

Before detailing the mining process, it is essential to briefly explain what a hashing algorithm is as it is plays a very important role in mining. A cryptographic hash function is a mathematical transformation that takes a message of arbitrary length and computes from it a fixed-length string (Kaufman et al., 2002). A hash function has some very important attributes:

i) for the same input, the output will always be the same;

ii) there is a different output for a different input; and

iii) the output does not reveal any information about the input data.

**BOX 1.** SHA 256 hashing algorithm

**Blockchain:**
EF7797E13D3A75526946A3BCF00DAEC9FC9-C9C4D51DDC7CC5DF888F74DD434D1

**Block chain:**
0B198ECB2A56B9F4765F9D9E0A8ADB2C6D-8231F17B2ED8ABCE9FB12512937C78

**SHA 256:** the two outputs are completely different even if the only difference between the inputs is a space ' ' character ('blockchain' – 'block chain')

### 1.3.3 Mining

In Bitcoin, the miner is a special entity in the system. **The miner's role is to verify transactions in a process called 'mining'.**

When Alice sends a transaction to Bob, it is not sent directly from one user to another. Instead, it is broadcast to the whole Bitcoin network and thus to all the nodes. However, at this point, the transaction has not been verified. It is in a pending state along with many other similar transactions worldwide. In order to be verified, the transaction must be included in the blockchain.

This is a task for the miners who collect pending transactions and stack them together in a predefined data type, the block. Apart from the transactions, the block also contains several block-specific data, such as time, block size, etc., and some random data put in by the miner. Next, the miner uses hashing to calculate the block's hash.

The block's hash will produce 64 characters, as seen in *Box 1*. The miner's goal is to produce a hash that starts with a predefined number of zeros, known as the 'difficulty'. As the miner cannot estimate which input is able to produce the desired output of having zeros as first characters, the only way to do so is to try as many inputs as possible and thereby to alter the parameters inside the block, especially the random nonce. When the desired hash has been found, the miner broadcasts the solution to the whole Bitcoin network. The network then verifies the correctness of the solution, the block is considered valid and is added to the end of the blockchain. The miner now moves on to solve the next block. As this process happens in parallel with all the miners worldwide, it is apparent that there is a continual race as to which miner will find a valid hash first and thus mine the new block.

The miner who finds the correct block earns 12.5 BTCs as a reward. These are new coins that have entered into circulation and did not belong to someone else before the reward. When Bitcoin was created, the reward was 50 BTCs. However, the Bitcoin algorithm is made in such a way that the reward is halved approximately every four years. Moreover, a new block is found in Bitcoin on average every 10 minutes.

**Apart from the reward, the miner earns all the transaction fees that are included in the transactions inside the new block. The reward and the transaction fees are an incentive for miners to keep mining,** even after all the BTCs are in circulation.

For a transaction to be verified, it must be stored in the blockchain. However, being present in the last block of the blockchain is usually not considered as secure enough. Due to the nature of the mining algorithm, the blockchain is not always linear. In some cases, a new block may be found at the same time by two different nodes, resulting in blockchain branches. In this case, one of the branches becomes the main branch and the other is disregarded. However, as this process requires several new blocks to be added to the blockchain, it can only be ascertained that this transaction has been verified after about six blocks, which in Bitcoin usually equates to an hour.

### 1.3.4 Consensus

The process of mining is the consensus algorithm used by Bitcoin to ensure trust in a non-trusted network. For someone to deceive the system and thus to be able to perform fraudulent transactions, she or he will need to have the majority of the Bitcoin network under her or his control, which is known as a '51 % attack'. Having the majority of the network on her or his side, she or he would be able to influence which blocks are or are not accepted in the blockchain and thus control which transactions are validated. **Using mining as a consensus algorithm is called 'proof of work' (PoW).**

**However, PoW has an important disadvantage: it consumes a huge amount of energy.** As the process of finding the correct hash and thus the next block is a race between all miners worldwide, having more computational power offers more chances to find the correct hash. Moreover, once one miner has found a new block, the work of all the other miners worldwide is considered useless. As the block they were working on probably contained some of the transactions that were included in the latest block, it can no longer be considered valid which means they must change its composition. Automatically, they must start the mining process for the new block from scratch. All their efforts towards the previous block no longer count, which also means that all the energy they have expended on these efforts has been wasted.

To better understand how much computational capacity is needed for mining, and thus how much energy is consumed, *Table 2* compares four different hardware components that are executing the SHA256 function. A powerful central processing unit (CPU) used in personal computers (i7 2600) can produce 24 million hashes per second. Even with this large number, it is statistically (almost) impossible to find a winning block in Bitcoin. The same applies for a GPU card, even though it can produce significantly more hashes per second, i.e. around 2 billion.

However, miners use special hardware, called Application Specific Integrated Circuit (ASIC), which is manufactured to only perform the SHA256 function. Using an ASIC improves the performance exponentially. However, even in this case, the chances of finding a block are few and the profits from the block discovery will not cover the expenses of the mining process (cost of hardware plus electricity consumption). What actually happens is that miners combine the processing capabilities of many ASIC machines, either alone or in groups, to achieve a processing power of hundreds of TH/s (tera hashes) which enables them to mine blocks.

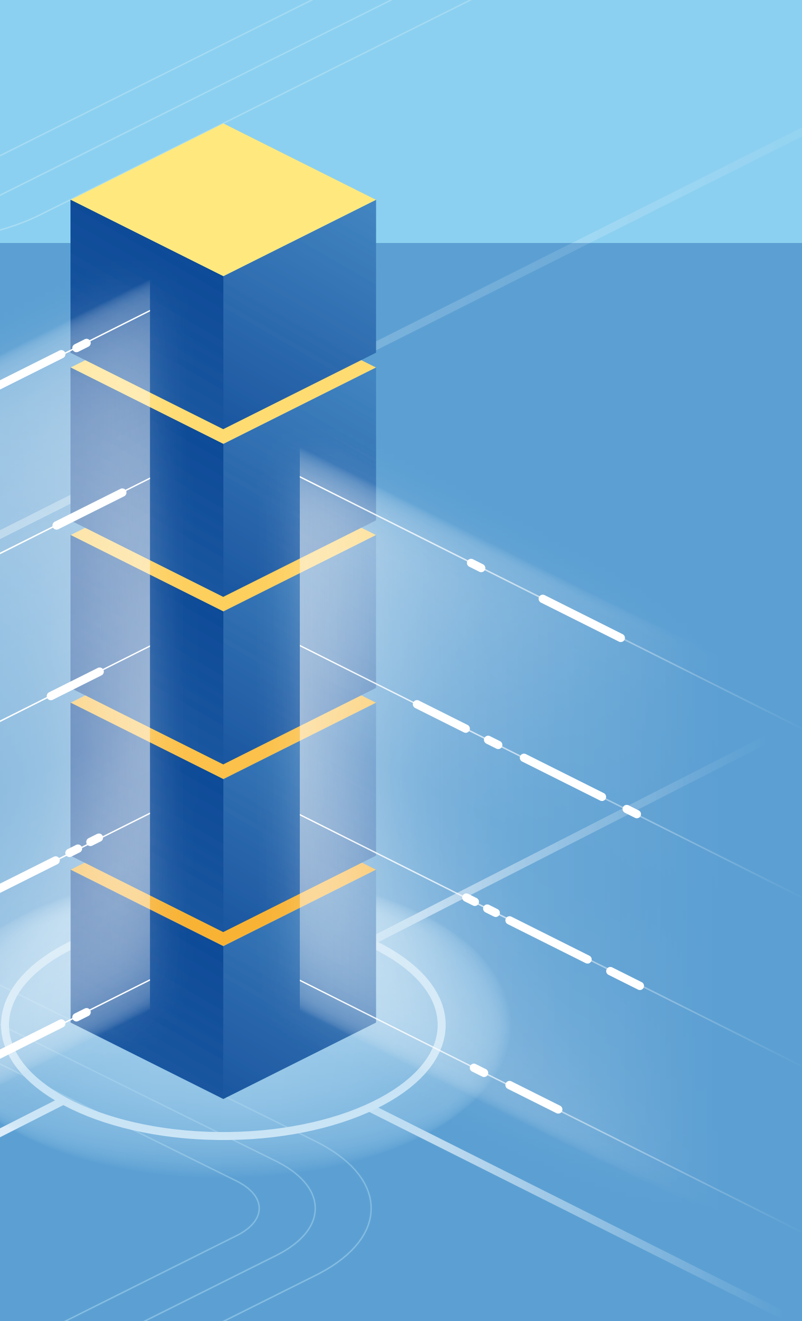
In response to this issue, many new consensus algorithms have been created to replace PoW, even though in practice very few of them are currently used. These algorithms are independent of the computational power held and, as a result, do not require any additional energy consumption by the miners.

The most popular is probably 'proof of stake' (PoS). In this consensus algorithm, mining power is distributed to those entities involved according to the percentage of coins they have. For example, if someone owns 10 % of all coins, she or he is able to mine 10 % of blocks. The use of PoS is much more energy efficient than PoW as the amount of computational power does not affect the mining probabilities.

Another example is the 'proof of authority' (PoA) consensus algorithm. Here, only approved accounts, called validators, can handle transaction validation and thus create new blocks. Every individual can become a validator. Moreover, reputation is linked to validators' digital identities, giving them an incentive to be honest and to continue validating to avoid being given a negative reputation.

| Hardware | Hashes per second (SHA 256) | Chances of finding a new block |
|---|---|---|
| CPU Core i7 2600 | 24 000 000 | Impossible |
| Graphic Card, AMD Radeon HD 7970 | 2 050 000 000 | Impossible |
| ASIC (Application Specific Integrated Circuit) - Antminer S9 | 14 000 000 000 000 | 1 block every 2 years |
| Bitcoin farms/mining pools | Hundreds of 1 000 000 000 000 | Probable |

**Table 2:** Mining capabilities – comparison of different hardware



# PART 2: LANDSCAPES

## SUMMARY

Blockchain has gone beyond just financial applications and has gained traction in many other sectors. It is anticipated that it will be one of the technologies making a profound impact over the next 10 to 15 years. Its rise is witnessed by both the sharp growth of blockchain start-ups and the volume of their funding. Massive funding started in 2014 and rapidly increased to EUR 3.9 billion in 2017 and over EUR 7.4 billion in 2018. Initial coin offerings (ICOs) have been driving funding to blockchain start-up ecosystem, but increasing inflows of venture capital to the sector mean a growing business maturity. There is strong competition from the USA and China, while the UK has a key role in the EU, together with Germany, France, Netherlands and Estonia. As for other international players, Switzerland and Singapore show particular dynamism, followed by Japan and South Korea.

# SCANNING BLOCKCHAIN ECOSYSTEMS

## 2.1. Anticipatory scoping

To a certain degree, since 2014, the hype around blockchain technology was influenced or shaped by a spike in interest from financial institutions. Projections over its impact quickly populated a closely watched space, ranging from estimations that DLTs could reduce banks' infrastructure costs by USD 15-20 billion per year by 2022 (Santander, 2015), to their ability to deliver USD 5-10 billion of savings for the reinsurance industry (PwC, 2016a), or store 10 % of global gross domestic products (GDP) by 2027 (WEF, 2015). Some of this hype was translated into pilots aimed at cross-border payments and settlements, securities trading, capital lending, or identity management, among other use cases.

But while more well-known applications in the financial sector were under development, **blockchain's broader potential for other sectors increasingly came to the fore** (Forbes, 2015; The Economist, 2014). A new set of players, from industry to academia, governments and supranational organisations, began reflecting on **how blockchain could transform significant parts of industry, the economy and society in the future** (Davidson et al., 2016; UK Government Chief Scientific Adviser, 2016).

The focus is now on how to leverage blockchain within other fields as part of the broader family of DLTs. This is now **one of the technologies expected to have a profound impact over the next 10 to 15 years** (OECD, 2016), backed in the short term by upward forecasts, such as the expectation that worldwide spending on blockchain solutions will reach USD 2.9 billion in 2019, an 88.7 % increase from the USD 1.5 billion spent in 2018 (IDC, 2019). Blockchain could be connected to new production trends or the 'fourth industrial revolution', which include other emerging technologies, from IoT to artificial intelligence and robotics, and new materials or additive manufacturing (OECD, 2017; Schwab, 2017; Craglia et al., 2018). Future scenarios powered by blockchain are also marked out by potentially profound changes in economic and governance models towards decentralised exchanges of value, or even more inclusive, transparent and accountable

> The rise of blockchain technology is witnessed by both the sharp growth of blockchain start-ups and the volume of their funding.

digital economies (Casey and Vigna, 2018; Mougayar, 2016; Tapscott and Tapscott, 2016).

### BOX 2. A high-level look into blockchain

In recent years, cryptocurrencies and more generally blockchain technology have been among the major debates within the World Economic Forum's activities and events. In their annual meetings at Davos in Switzerland, public statements, dedicated sessions and side events on blockchain have shifted from cautionary approaches to more positive remarks, now targeted at its potential broader impact across sectors. The WEF's Centre for the Fourth Industrial Revolution, created in 2017, has also produced a number of outputs, from the 'Blockchain Transformation Map' – a dynamic knowledge tool to understand the main issues and forces associated with its deployment – to the 'Blockchain Beyond the Hype' practical framework (WEF, 2018) – designed to help stakeholders understand whether blockchain is appropriate for their business needs. The Global Council on Blockchain was also formed to help shape the global technology policy and corporate governance agenda in the space. The Council's 30 members include ministers and heads of regulatory agencies, chief executive officers, and leading technical and civil society experts.

**However, much of blockchain's potential still seems unfulfilled or has yet to be fully tested** (Gartner, 2018a). Core technical issues remain unresolved, such as scalability and performance of public blockchains mainly related to the low volume of transactions; potential collusion or concentration when a majority of participants could overrun the network; high energy consumption when deploying current PoW consensus mechanisms; or protection of personal, sensitive or confidential data in blockchain-based applications designed to be transparent and tamper-resistant – among others related to legal and institutional hurdles.

At the same time, **as regards its economic impact, recent analyses give mixed signals.** A large majority (77 %) of chief information officers acknowledged that their organisation had no interest or plans to investigate or develop blockchain systems, and only 1 % identified any form of blockchain adoption within their organisations (Gartner, 2018b). Also, a high rate of projects are either abandoned or do not achieve a meaningful scale (Deloitte, 2017). When it comes to ICOs (see *sections 2.2 and 4.2* for more details), over half of the projects become inactive in four months (Benedetti and Kostovetsky, 2018), while over 80 % (by share) were identified as scams in 2017 (Satis Group, 2018).

The period up to 2021 is now seen by some as an 'irrational exuberance', and only in the next phase of 'larger focused investments' is the business value added of blockchain predicted to grow up to USD 360 billion by 2026 (Gartner, 2018c).

However, alongside misgivings concerning the impact of blockchain, its added value, or concrete paths for its widespread deployment, **signs of compelling possibilities for its application and potential growth are becoming worthy of attention.**

## 2.2. EU and global trends

Blockchain technology is still in its infancy. One practical consequence of this young age is the lack of industrial statistics dedicated specifically to blockchain firms. The following analysis presents trends in blockchain start-ups identified by a JRC-built dictionary of keywords[5] from the Venture Source database which contains verified data on companies. This database collects detailed information about companies receiving funding from private investors or public sources. Matching the dictionary of keywords and the descriptions of company profiles provided 1 241 unique blockchain firms – established in 2009 at the earliest – of the overall 146 297 companies included in this database[6].

> Within the EU, the United Kingdom hosts *almost half of the blockchain start-ups, followed by Germany, France and Estonia.*

## Trends in the number of blockchain start-ups

As of 31 December 2018, the **largest number of blockchain firms was established in the USA, followed by China. The EU lags in this classification with only a 15 % share in the global blockchain start-up ecosystem** *(see Figure 5, panel A).*

*Panel B* gives the breakdown in the total number of blockchain start-ups in the EU across Member

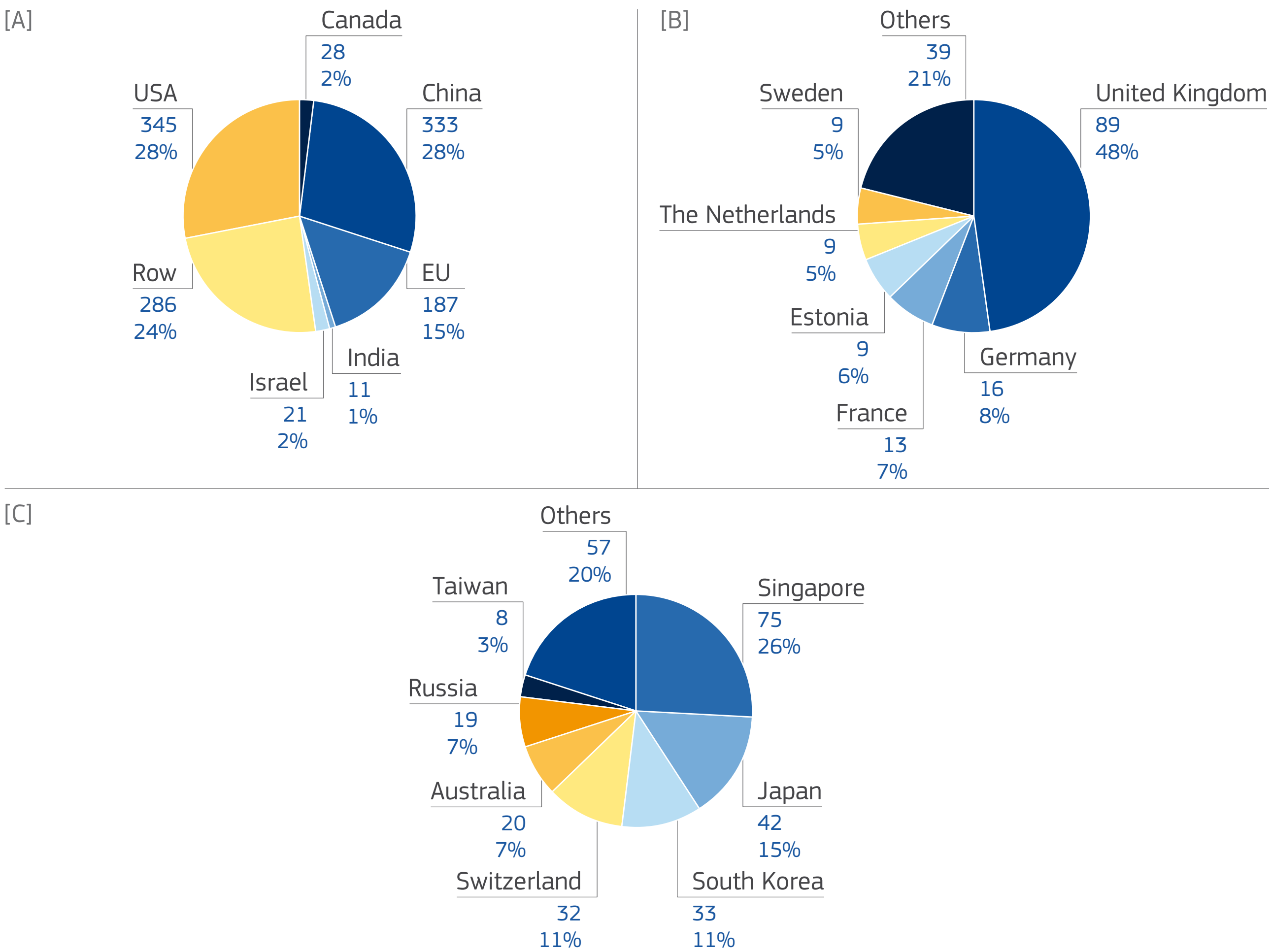



**Figure 5:** Numbers and shares of blockchain start-ups established between 2009–2018 across: [A] key world players; [B] EU Member States; [C] the rest of world

**Source:** Venture Sources - Dow Jones

States. **The United Kingdom hosts almost half of the EU blockchain start-ups, followed by Germany, France and Estonia with shares of 8 %, 7 % and 6 %, respectively.**

*Panel C* shows the breakdown in the number of start-ups for the rest of the world (RoW) (i.e. apart from Canada, China, the EU, India, Israel and the US). In this respect, **Singapore, Japan, South Korea, Switzerland, Australia and Russia stand out** as home to two digit numbers of blockchain start-ups. Perhaps the most striking observation that follows from *Figure 5* is that, all in all, **blockchain ecosystems are flourishing mainly in developed economies.**

The entry dynamics of new blockchain start-ups across the main world players is illustrated in *Figure 6.* Starting from 2010, **the number of new start-ups entering the blockchain industry each year rose steeply worldwide until 2017, at an average annual rate of 40 %** (dashed line). This increase is particularly apparent in the USA, China and Europe. **In 2018, the new entry shrank remarkably in the USA, the EU, RoW and also globally. In 2018, only China recorded higher additions of new start-ups, compared to the previous year.**

Yet it is premature to acknowledge this one year anomaly as a change in the global trend. However, if the change is confirmed in 2019, this may indicate that globally the industry is approaching saturation point with respect to new firms. This hypothesis is supported by the recent shift from crowdfunding and ICOs towards regulated and institutionalised forms of funding, such as venture capital. This change in the structure of funding indicates that (still increasing) investment is now being channelled mainly to already established firms to finance the scale-up phase of successful projects.

## Trends in the profiles of blockchain start-ups

*Figure 7* provides a global snapshot of blockchain start-ups by the main types of economic activity. **Two sectors in particular predominate: 'Business and Financial Services' (672 firms) and 'Information Technologies' (568).** The first sector encompasses firms that deal with payments and transaction processing, investment services, data management, advertising and marketing.

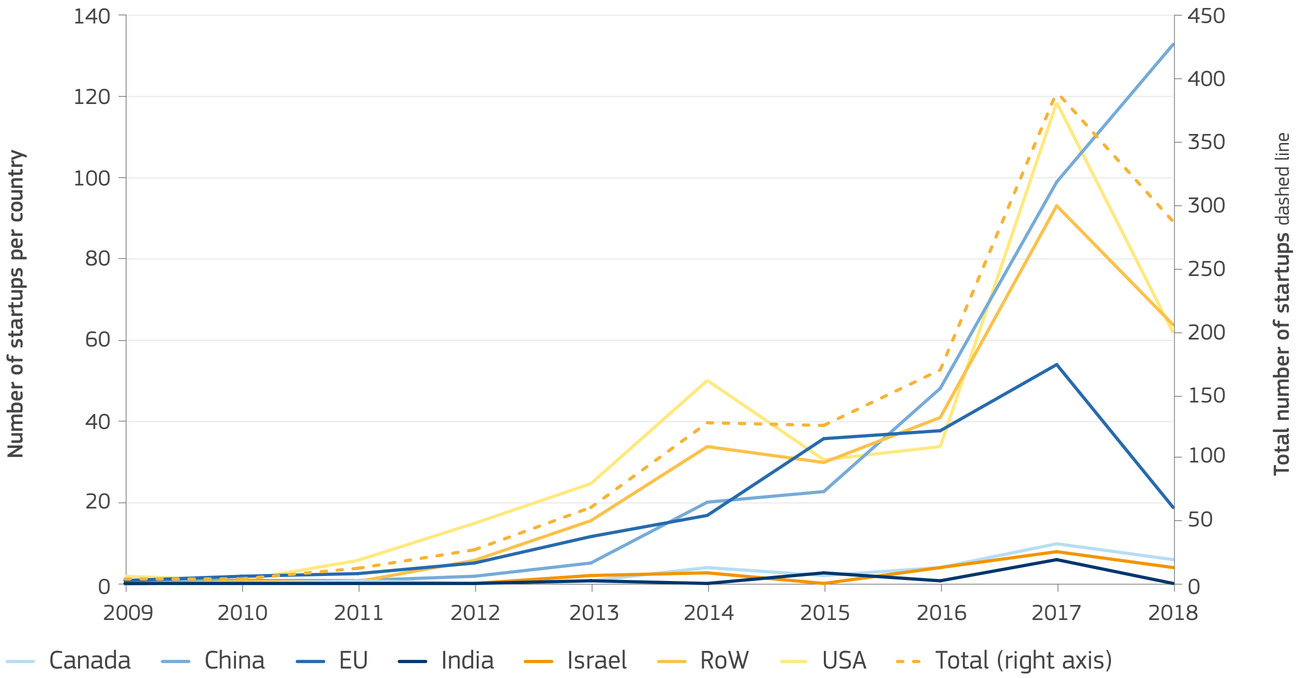



**Figure 6:** Trends in total blockchain start-ups across the main world players
**Source:** Venture Sources - Dow Jones

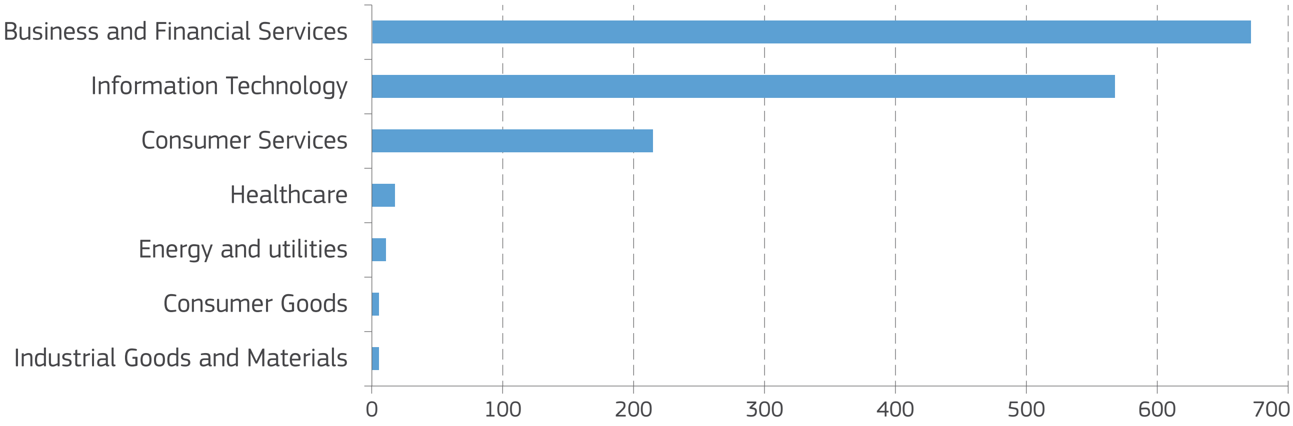



**Figure 7:** Blockchain start-ups across sectors of economic activity
**Note:** 1 211 firms of which 283 are operating in more than one sector
**Source:** Venture Sources - Dow Jones

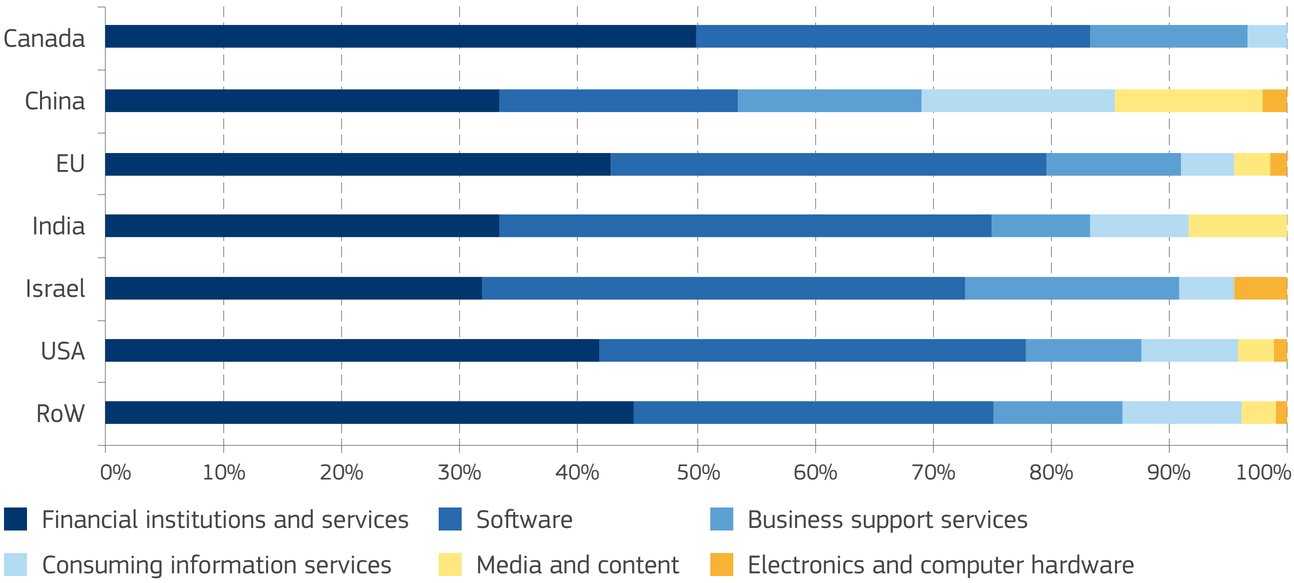



**Figure 8:** Industrial profiles of start-ups across the main world players (2009-2018)
**Note:** Only categories with more than 15 start-ups worldwide are presented
**Source:** Venture Sources - Dow Jones

The second one includes IT firms developing software for business applications, vertical markets applications, network management, databases as well as recreation and healthcare. Blockchain start-ups are also classified in the 'Consumer Services' sector (215), which provides services related to online communities, general media and content, shopping facilitation as well as education, training and entertainment.

*Figure 8* presents profiles of blockchain start-ups across the main world players, based on the more detailed industrial classification[7]. **The industrial profiles are quite homogenous across the three main regions: the USA, the EU and RoW.** Over 70 % of start-ups in these regions develop financial services or software. Another 10 % are classified in business support services. China, which is a leader in the number of start-ups, has a more diversified and balanced profile with some 12 % of its start-ups operating in the media and content sector, and some 16 % in consumer information services. Overall, in the USA and the EU, blockchain firms are quite concentrated in only a few industrial categories focused on the development of software, as well as financial and business services, while Chinese companies pay greater attention to blockchain applications in consumer-related fields.

## Trends in funding blockchain start-ups

*Figure 9, panel A* illustrates global amounts (EUR million) invested in blockchain start-ups across the main world players between 2009 and 2018. **The US firms received the most funding, totalling EUR 4.4 billion. Companies from the EU received EUR 2.9 billion in investments, followed closely by start-ups from China (EUR 2.8 billion).** Overall, the **global level of funding of all types, including venture source, grants and ICOs exceeded EUR 13.1 billion** for the whole period. **Companies established in other regions (RoW, Canada and Israel) have only 23 % share** of the global investment in blockchain start-ups[8].

*Panel B* presents a breakdown of investments among EU Member States. The United Kingdom's dominant role is even more apparent than in the case of the number of blockchain firms shown in *Figure 5.* **Firms established in the United Kingdom received almost 70 % (i.e. EUR 2 027 million) of total funding in the EU. The Netherlands come next with blockchain start-ups funded at a level of EUR 352 million. Companies in France received EUR 167 million, followed by Estonia and Germany (EUR 110 and 97 million, respectively).**

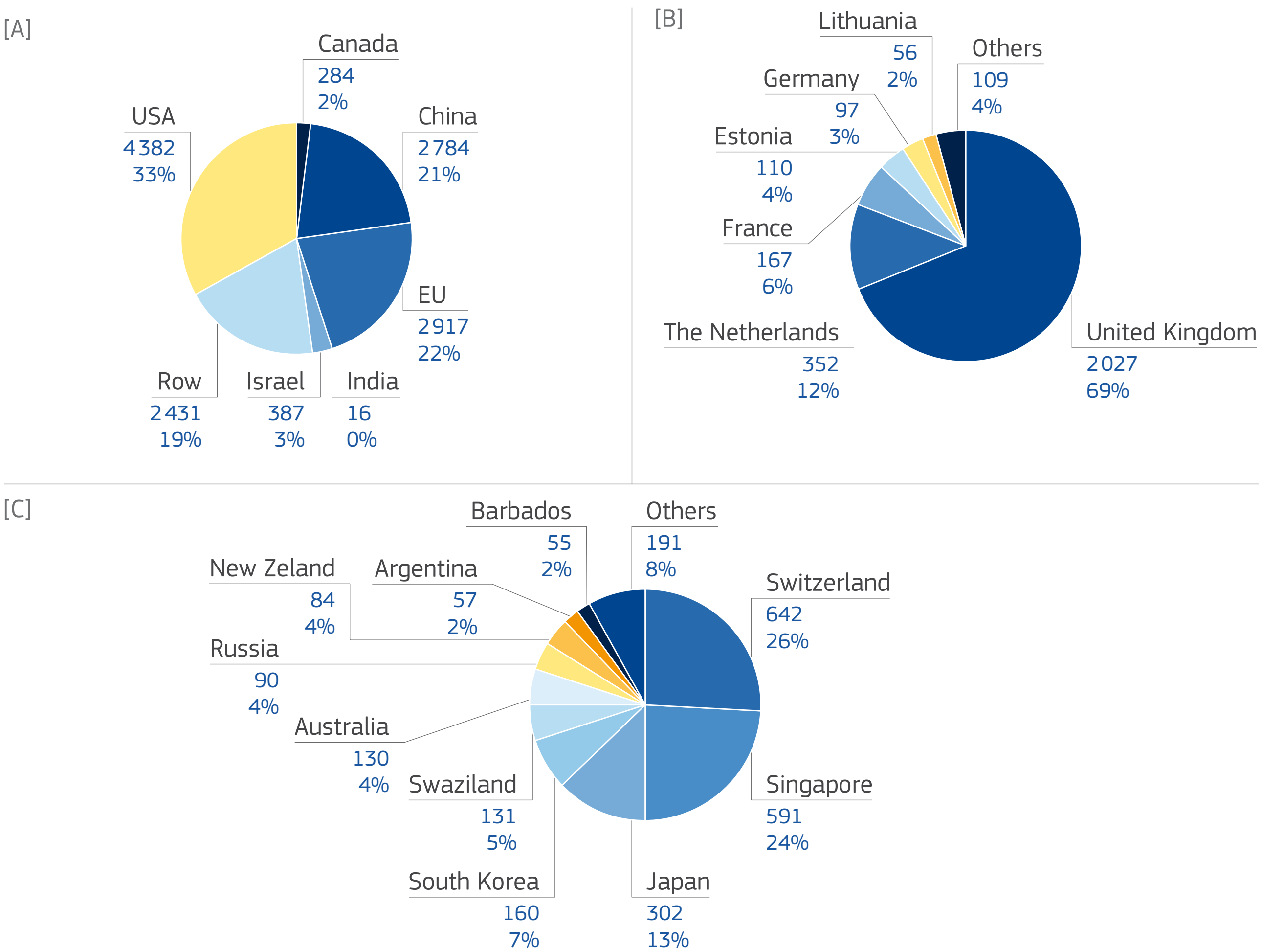



**Figure 9:** Shares and amounts (EUR million) received via all funding mechanisms by blockchain start-ups between 2009–2018 across: [A] key world players; [B] the EU Member States; [C] the rest of world
**Source:** Venture Sources - Dow Jones

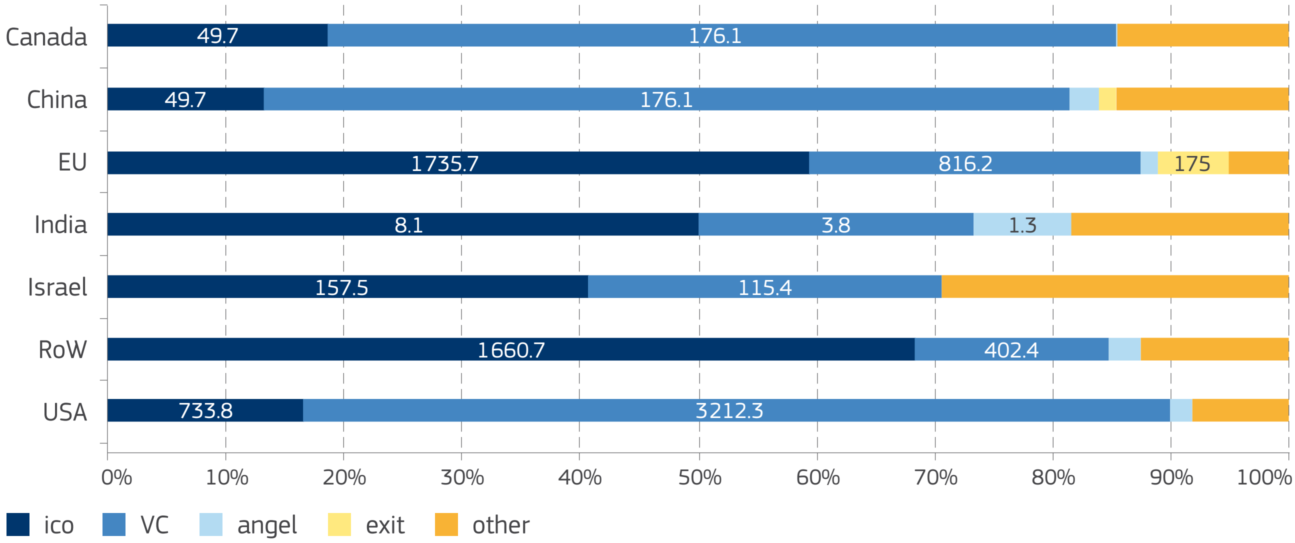



**Figure 10:** Shares and amounts (EUR million) invested in blockchain start-ups via different funding instruments in main world players (2009-2018)
**Note:** The category labelled 'other' includes equity-based funding, private and public grants and accelerator funds. The 'exit' category contains acquisitions and initial public offerings.
**Source:** Venture Sources - Dow Jones

*Panel C* presents country-level insight for countries grouped in the RoW category. **Blockchain start-ups from Switzerland, Singapore, Japan, South Korea, Swaziland and Australia attracted the greatest funding** (EUR 642, 591, 302, 160, 131 and 130 million, respectively). Interestingly, **only six developing countries are listed above the threshold of EUR 50 million: Swaziland, Estonia, Russia, Argentina, Lithuania and Barbados,** which confirms the former observation that blockchain technology is being developed and financed predominantly in developed countries.

*Figure 10* provides an overview of the structure of the funding mechanisms providing investments in blockchain start-ups. **The two largest sources are venture source funds (EUR 6 634 million) and ICOs (EUR 4 716 million)**[9]. A significant amount of funding was provided by public and private grants and accelerator funds (EUR 1 369 million). The role of business angels in blockchain companies appears to be very small (EUR 257 million). It is noteworthy that exits from the investment in blockchain firms via acquisitions, buyouts or initial public offerings are almost non-existent. This indicates that the market value creation from blockchain technology is still in the early stages[10].

Looking at the proportions of the two dominant sources across geographic regions, it is evident that **venture capital plays a major role in the USA, Canada and China, where it provides**

> The two largest funding sources are venture capital funds *(EUR 6 634 million) and ICOs (EUR 4 716 million).*

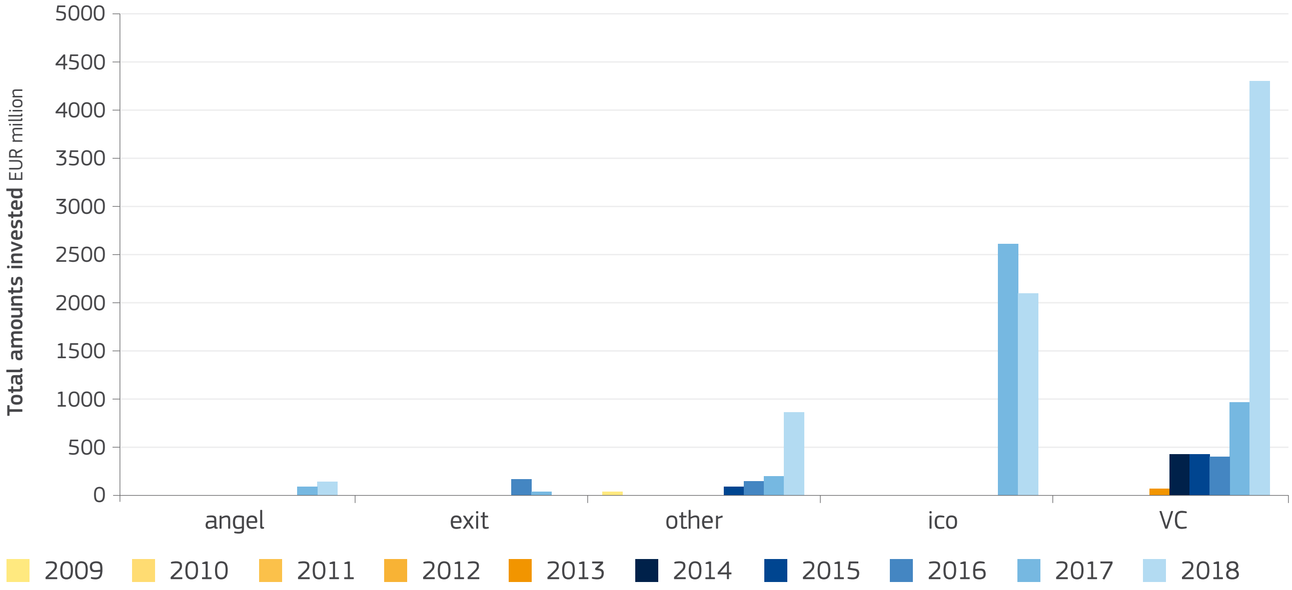



**Figure 11:** Total amounts (EUR million) invested in blockchain start-ups across different funding instruments (2009-2018)
**Note:** The category labelled 'other' includes equity-based funding, private and public grants and accelerator funds. The 'exit' category contains acquisitions and initial public offerings.
**Source:** Venture Sources - Dow Jones

**66-73 % of total investment. At the other extreme, blockchain start-ups from India, the EU, and the rest of world rely mainly on ICOs, which account for 50-68 % of the total funding.** The reversed roles of venture capital vs. ICOs comprise the most striking difference between the USA and the EU with respect to the capital supply for blockchain start-ups.

Finally, *Figure 11* presents the dynamics of global investment flows in blockchain start-ups across different funding instruments. Regular investments in blockchain start-ups began in 2014. Until the end of 2016, blockchain firms were receiving funding mainly from venture capital and also in part from grants (classified as 'other' in *Figure 11*), although the overall level of investment was modest. From 2014 to 2016, overall the total investments grew at an annual rate of 30-40 %, hitting EUR 720 million in 2016 from all instruments.

The **investment in blockchain start-ups exploded in 2017, reaching a total of EUR 3.9 billion. ICO was the most prominent instrument (EUR 2.6 billion) that year and the main driving force for the start-up ecosystem.** ICO has itself been enabled by blockchain technology and leverages cryptocurrencies to finance all types of start-ups that issue their own tokens.

In **2018, significant funding for blockchain start-ups continued to flow via ICOs and venture capital funds which hit EUR 7.4 billion in total.** It is noteworthy that grants and equity-type funding also rose significantly during that year (EUR 968 million). This indicates that, together with venture capital, there was an obvious shift towards more institutionalised, more professionalised and also more concentrated forms of investor participation and control in the blockchain industry. Interestingly, between 2017 and 2018, the average amount per venture capital round sharply increased from EUR 8 to 15 million, while on average each ICO provided stable but larger amounts in both years (EUR 26 and 28 million, respectively).

In terms of key takeaways, the above-mentioned analysis underlines the following:

- **Blockchain start-ups started to emerge in 2009. The attention of worldwide investors shifted to blockchain companies a few years later. The first significant investment came in 2014 from venture capital funds (EUR 412 million).**

- The rise of blockchain technology is witnessed by both the **sharp growth in blockchain start-ups and by the volume of funding** going into them.

- **The massive funding started in 2014 with EUR 450 million and rapidly increased, reaching EUR 3.9 billion in 2017 and over EUR 7.4 billion in 2018. In 2017, the amount of invested capital grew on an unprecedented scale, due to the explosion of ICOs and venture capital investments** which continue at a high rate in 2018.

> “Massive funding started in 2014 with EUR 450 million and rapidly increased, *reaching EUR 3.9 billion in 2017 and over EUR 7.4 billion in 2018.*”

- ICO is a new form of funding that has been enabled by blockchain technology. It leverages cryptocurrencies to finance early stage activities of start-ups that issue their own non-equity tokens. ICOs have been the initial force driving large funding to the blockchain start-ups ecosystem in 2017.

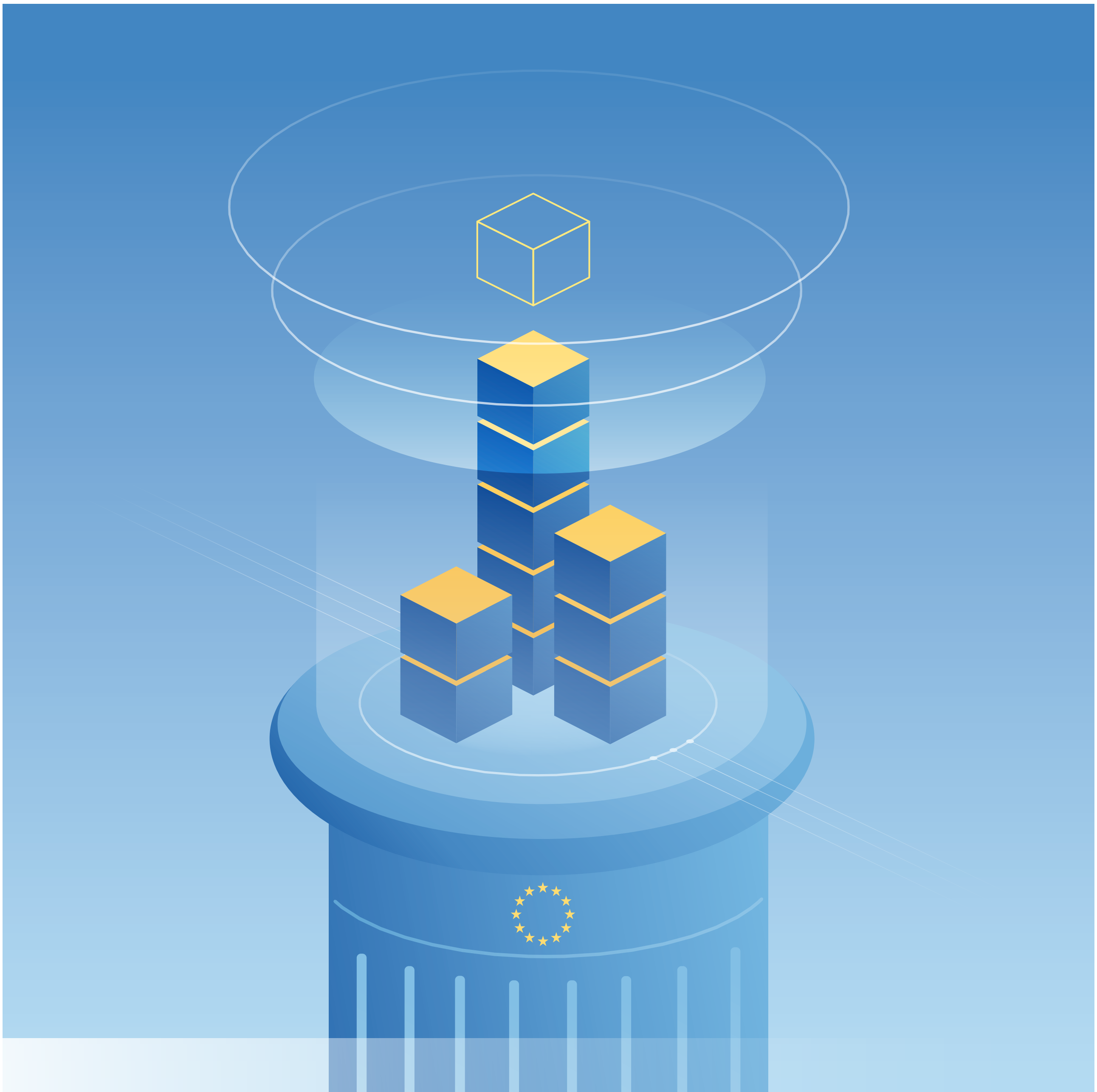
- While ICO is a non-equity fundraising instrument that serves to kick-start new ideas, **increasing inflows of venture capital to the sector mean a growing business maturity of blockchain projects.** The participation of more professionalised and institutionalised investors is likely to have consequences for the further development of the ecosystem, starting from product and platform choices and ending with strategic alliances and international competition.

- Worldwide, the **USA and China appear to lead in terms of blockchain start-ups.**

- **The UK has a key role in the EU both in terms of numbers of blockchain start-ups, and in the funds channelled into them.**

- When taking a broader look to international players, **Switzerland and Singapore show particular dynamism in harvesting blockchain start-ups,** followed by Japan and South Korea.

- The participation of developing countries in blockchain technology appears to be somewhat less significant with only EUR 0.5 billion of overall funding with ICOs as a primary source of capital.




## SUMMARY

The growth of and increasing attention to blockchain has not gone unnoticed at EU policy level. Initially, the main focus was placed on the emergence of crypto-assets and virtual currencies such as Bitcoin. However, its potential as an emerging technology across a number of sectors has been publicly recognised and promoted in recent years by European institutions and authorities. For instance, a range of calls, research programmes and funding for third parties is at the core of the European Commission's support for experimentation and innovation. A number of EC services are also conducting, starting with or reflecting on exploratory activities using blockchain as possible ways to improve and support core processes and policies, such as the accessibility of regulated information, real-time reporting, management of identities, notarisation services, and monitoring the movement of goods.

# BLOCKCHAIN IN THE EU POLICY CONTEXT

## 3.1. FinTech and crypto-assets

At first, the main focus at the EU policy level was on the emergence of crypto-assets and virtual currencies such as Bitcoin. **In November 2016, the EC in collaboration with the European Parliament (EP) set up a horizontal task force on FinTech with a dedicated group on DLTs,** following the EP Resolution on virtual currencies (EP, 2016).

In particular, the Resolution underlined the potential of DLTs for the financial sector when it came to payments, especially the cross-border transfer of funds. On a broader scale, the Resolution also acknowledged its potential to transform any kind of data-driven processes that imply recording of transactions and transfer of assets, including for instance, clearing, settlement and other post-trade management processes, crypto-equity crowdfunding, and dispute mediation services, in particular in the financial and juridical sectors using smart contracts, for example.

At the same time, while acknowledging a number of opportunities and risks, it pointed to the need for enhanced regulatory capacity, including technical expertise, the development of a sound legal framework, and the promotion of shared and inclusive governance of the DLT (for instance, through the creation of a Dynamic Coalition on Blockchain Technology at the Internet Governance Forum). Overall, the Resolution was positive towards the potential of DLTs and mainly called for a proportionate regulatory approach at EU level with the explicit goal not to stifle innovation.

> Blockchain's potential across sectors has been publicly recognised and promoted in recent years by European institutions and authorities.

In particular, the discussion on virtual currencies was also framed at the time by ongoing negotiations on the amendments to the 4th Anti-Money Laundering Directive (AMLD), which were concluded and published on 19 June 2018 as the 5th Anti-Money Laundering Directive (Directive (EU) 2018/843). To be implemented by the Member States by 10 January 2020, this Directive brings cryptocurrency exchanges and custodian wallet providers within the scope of EU regulation – that is, obligated to implement mechanisms to counter money laundering and terrorist fundraising, such as 'know your customer' (KYC). A cautious and at times adverse view on the deployment of virtual currencies has been expressed at the EU level, for instance by the European Central Bank (ECB) *(see section 4.1).*

Other recent assessments by European supervisory authorities (ESAs) have focused on the potential implications of crypto-assets for financial stability and the suitability of existing EU and national financial regulatory frameworks *(see section 4.2).*

Still focusing on DLTs and blockchain financial applications, on 23 March 2017, the EC launched the public consultation on FinTech (EC, 2017e). Its purpose was to seek input from stakeholders to further develop the Commission's policy approach towards **FinTech, defined as technological-enabled innovation in financial services** (EC, 2018, p.2). DLTs were identified as an area where EU action could potentially be beneficial for its uptake through an assessment of critical technological and regulatory challenges *(see section 4.4)* and possible solutions for its implementation.

Following the consultation, the **FinTech Action Plan** (EC, 2018) was published on 7 March 2018 and highlighted blockchain and DLTs, digital identification, mobile applications, cloud computing, big data analytics and artificial intelligence as new technologies that are changing the finance industry and the way consumers and firms access services. Drawing on the conclusions from the consultation and taking account of ongoing EU initiatives, the Action Plan considered that **broad legislative or regulatory action or reform at EU level at this stage has a limited scope, taking into account DLT is still at an early stage of development.** Here again the policy emphasis is on assuring basic conditions and safeguards without stifling innovation.

A number of targeted initiatives for the EU were underlined by the Action Plan to further embrace digitalisation of the financial sector. When it comes to DLTs, an **assessment of the suitability of the current EU regulatory framework** with regard to crypto-assets and ICOs, as a new way of raising money using the so-called 'coins' or 'tokens' is deemed necessary. It follows the previous and ongoing monitoring of EC developments with the ESAs, the ECB and the Financial Supervisory Board (FSB) as well as other international standard setters.

Another initiative mentioned concerns **identifying best practices across the EU and setting up common principles and criteria for innovation hubs and regulatory sandboxes.** On the one hand, such environments could enable firms to gain quicker access to the market and better understand the rules and supervisory expectations. On the other hand, they could provide relevant sources of information for supervisors and regulators, helping them to better understand emerging business models and market developments.

> "Broad legislative or regulatory action or reform at EU level has a limited scope so far, *as DLTs are still at an early stage of development.*"

The Action Plan explicitly acknowledged the extra novelty of regulatory sandboxes in the sense that they provide firms with a controlled space in which innovative solutions can be tested with the support of an authority for a limited period of time. Considering ongoing programmes such as those in the UK, Australia, Hong Kong, Switzerland, Singapore, Canada, Indonesia, Malaysia, Taiwan, Thailand and Japan, among others (FCA, 2017; ASIC, 2017; CDC, 2017), regulatory sandboxes usually imply a degree of discretion as regards application of the proportionality and flexibility principles. This discretion is recognised by the FinTech Action Plan as potentially useful in the context of technological innovation.

## 3.2. Cross-sectorial initiatives

At EC policy level, blockchain is considered to be 'one of the breakthrough technologies which can have a huge potential impact in the financial sector, but also far beyond' (EC, 2017c). That is, 'blockchain technologies can transform digital services, moving away from centralised platform models and can be applied to different domains: eHealth services, eGovernment and social goods delivery, energy, supply chains, IoT, the financial sector and others' (EC, 2017d). In addition, in the domain of international development, blockchain-secured transactions were identified as one of possible digital solutions that 'can help combat poverty, contribute to better targeting and the linking of humanitarian and development activities, and help to manage migration and address shortcomings in a number of EU partner countries' (EC, 2017b).

The advantages of deploying blockchain technology include, for instance, 'transparency and auditability' which have 'the potential to empower citizens' control and help reduce fraud and compliance costs for public authorities and supervisors' (EC, 2017d). Yet a number of unresolved issues, including scalability, governance, interoperability and legal and regulatory aspects, such as challenges to traditional civil and contract law concepts and rules (EC, 2017a), were also identified at EU policy level.

Several strategies on how to approach these broader realities of blockchain are being explored by European institutions and authorities.

Within the context of the horizontal task force on FinTech, supported by the EP, the EU **Blockchain Observatory and Forum**[11] was launched in February 2018. This aims to monitor trends, developments and use cases, pool expertise to address sectoral and cross-sectoral issues, and explore joint solutions and cross-border use cases. Under the aegis of the EC's Directorate-General for Communications Networks, Content and Technology (DG CNECT), partners include ConsenSys AG, the University of Southampton, UK, the Knowledge Media Institute at the Open University, University College London, UK and the Lucerne University of Applied Sciences in Switzerland.

Among its activities, the EU Blockchain Observatory and Forum has put together two thematic working groups (on Blockchain policy and framework conditions and on use cases and transition scenarios), each comprising around 30 members. It has also released a number of thematic reports, such as on Blockchain Innovation in Europe (July 2018), Blockchain and the GDPR (October 2018), Blockchain for Government and Public Services (December 2018), Scalability, Interoperability and Sustainability of Blockchains (March 2019), and Blockchain and Digital Identity (May 2019)

Since April 2018, 26 Member States plus Norway and Liechtenstein have signed a Declaration creating the **European Blockchain Partnership (EBP)**[12]**.** The aim is to cooperate in setting up a **European Blockchain Services Infrastructure (EBSI)** to support the deployment of cross-border digital public services. The ambition of the partnership is to develop an infrastructure accessible to support digital services deployed by the public sector and eventually by private actors, too. This development is also informed by an ongoing feasibility study supported by the EC to assess the conditions of an EU Blockchain Infrastructure (EuroChain) within an open, innovative, trustworthy, transparent, and EU-law-compliant data and transactional environment[13].

In the EU Blockchain Roundtable held in Brussels on 20 November 2018, the EC and the European Blockchain Partnership announced the decision to launch the International Association for Trusted Blockchain Applications (IATBA) in 2019. The idea is to gather multiple stakeholders from industry, start-ups, governments, international organisations and civil society that are actively engaged in blockchain and DLT programmes. Governmental organisations, standard-setting bodies and international organisations are invited to join the Association as observers. Its main goals are to:

- maintain a dialogue with public authorities and regulators that will contribute to the convergence of regulatory approaches to blockchain at a global scale;
- promote an open, transparent and inclusive global model of governance for blockchain and other DLT infrastructures and applications;
- support the development and adoption of interoperability guidelines, specifications and global standards, to enhance trusted, traceable, user-centric digital services; and
- develop sector-specific guidelines and specifications for the development and acceleration of trusted blockchain and DLT applications in specific sectors (i.e. financial services, health, supply chain, energy and financial inclusion).

Within activities developed over the past two years, the EC is also supporting **standardisation efforts** within the International Organization for Standardization (ISO) (JRC researchers are participating in all of its study and working groups on ISO/TC 307[14]), the International Telecommunication Union (ITU) (Focus Group on Application of Distributed Ledger Technology[15]), the European Telecommunications Standards Institute (ETSI) (Industry Specification Group on Permissioned Distributed Ledger[16]), and CEN-CENELEC (Focus Group on Blockchain and Distributed Ledger Technologies[17]). The latter has recently published a White Paper (CEN-CENELEC, 2018) with a series of recommendations on priority topics, such as sustainable development, digital identity, privacy and data protection, and highlights specific European use cases in the areas of financial services and asset management (including KYC), registry services/licence management, asynchronous/distributed automation, data protection and information security, identity management, fundraising (through tokens), smart energy grids and smart homes/cities.

In February 2019, the EC's Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) announced that the European Union Intellectual Property Office (EUIPO) launched the **Anti-Counterfeiting Blockathon Forum**[18]. This will bring together people and organisations to define an anti-counterfeiting use case and related pilot, and ultimately to shape and deliver a future blockchain-based anti-counterfeiting infrastructure. To this end, the Forum intends to interconnect private organisations, enforcement authorities and citizens to support the identification of authentic and counterfeit goods throughout the distribution chain.

This Forum is the follow-up to the **EU Blockathon competition** held in Brussels from 22 to 24 June 2018, with the purpose of harnessing the potential of blockchain technology to protect supply chains against counterfeits. During the event, 11 teams of coders worked for 48 hours to co-create a series of anti-counterfeiting blockchain solutions for consumers, enforcement authorities, logistic operators and businesses[19].

Previously, the EUIPO was actively engaged in reflections around the implications of blockchain on intellectual property (IP). For instance, on 27 October 2017, it organised a conference on Blockchain and Intellectual Property in Alicante[20], which covered basic concepts of the technology, interactions between the technology and IP, and three practical use cases (supply-chain protection, music management, and tracing BTCs). Participants included blockchain experts, national IP offices, rights holder representatives and representatives from civil society.

In parallel, the EP is also actively engaged in past and ongoing discussions about the cross-sectorial potential of this technology. On February 2018, the European Parliamentary Research Service, in particular its Scientific Foresight Unit (STOA) published the **report 'How Blockchain Technology Could Change Our Lives',** aimed at stimulating reflection and discussion (Boucher et al., 2017). It begins by acknowledging that blockchain technology is complicated, controversial and fast-moving, although of increasing interest to citizens, businesses and legislators across the EU. The report looks at eight areas in which blockchain has been described as having a substantial potential impact (currencies, digital content, patents, e-voting, smart contracts, supply chains, public services, and decentralised autonomous organisations), and explains how the technology could be developed in those particular areas, the possible impacts this development might have, and what potential policy issues should be anticipated.

On 3 October 2018, the **EP Resolution on 'Distributed Ledger Technologies and Blockchains: Building Trust with Disintermediation'** (EP, 2018a) also highlights a wide range of DLT-based applications that could potentially affect all sectors of the economy, such as energy, transport, healthcare, supply chains, education, creative industries and financial services, among others. It provides a positive outlook on their potential effects, such as improving trust and transparency, reducing transaction and intermediation costs, improving organisational efficiency, and empowering citizens to control their own data.

It emphasises in particular how the EU has an opportunity to 'become the global leader in the field of DLT and to be a credible actor in shaping its development and markets globally'. To that effect, it states that blockchain and DLTs need an 'innovation-friendly, enabling and encouraging framework' which is able to provide regulatory and legal certainty and guarantee consumer, investor and environmental protection. In addition, such framework should

> "The EC is supporting multi-stakeholder initiatives that gather *industry, start-ups, governments, international organisations and civil society.*"

respect the 'principle of technology neutrality and business-model neutrality'.

On 13 December 2018, the **EP Resolution on 'Blockchain: A Forward-Looking Trade Policy'** (EP, 2018b) looks in particular into how blockchain can enhance and improve EU trade policies. For instance, it stresses that blockchain could potentially support the trade and sustainable development (TSD) agenda by improving trust in the provenance of raw materials and goods and enhancing transparency in production processes and supply chains when it concerns their regulatory compliance with labour, social and environmental rights (including in the fields of conflict minerals, illicit trade in cultural goods, export control and corruption).

Similar to the previous Resolution, this one underlines the importance for the EU to show leadership and ownership in the field of blockchain. It stresses the need for a 'level playing field' when it comes to global competition and an enabling development and regulatory environment, while stating that 'legislating the technology forming the basis of the applications would limit innovation and the creation of new applications'. Finally, it calls for a number of actions for the EC and Member States to undertake, such as to launch and supervise pilot projects to test its benefits; to develop a set of guiding principles for blockchain application to international trade (to provide a sufficient level of legal certainty); and to play a leading role in the process of blockchain standardisation and security, including terminology, development, and deployment of the technology in trade and supply-chain management, among others.

## 3.3. Financing and support

A range of calls, research programmes and funding for third parties is also at the core of the EC's support for experimentation and innovation concerning blockchain and DLTs.

> "#DLT4Good focuses on research and experimentation of DLT solutions *suited to specific challenges of public and third-sector organisations.*"

In 2018, DG GROW launched a **call on 'Blockchain and Distributed Ledger Technologies for SMEs'** (INNOSUP-03-2018)[21], which further attests to its mounting attention to the possibilities of blockchain in the EU industrial and business contexts, with a key focus on the innovation and competitiveness capacity of small and medium-sized enterprises (SMEs).

The winning project, BLOCKCHERS[22], will implement a two-phase funding scheme and support SMEs selected in two open calls. One of its goals is to foster matchmaking among traditional SMEs and potential DLT specialists, as technology providers, and sensitise stakeholders about the benefits and opportunities around DLTs to implement real-use-case scenarios. At least 60 SMEs will benefit from this scheme. The best group (up to 30) of SMEs working with DLTs on use cases with traditional SMEs will be selected.

Each group can obtain up to EUR 50 000 in equity-free funding plus a range of free services.

As another example, in May 2018, the EC opened the **European Innovation Council (EIC) Horizon Prize for Blockchains for Social Good**[23]**,** to be allocated in five awards of EUR 1 million each and awarded at the beginning of 2020. The challenge is to develop scalable, efficient and high-impact decentralised solutions to social innovation challenges leveraging on DLTs. It is targeted at a multidisciplinary range of actors, such as individuals, social entrepreneurs, civil society organisations, research centres from technological and social disciplines, creative industries, students, hackers, start-ups and SMEs. For the purpose of this prize, areas for application of social innovations leveraging on decentralised solutions based on DLTs include, for instance:

- demonstrating the origin of raw materials or products and supporting fair trade and the fair monetisation of labour;
- allowing for a greater visibility of public spending and a greater transparency of administrative and production processes;
- participation in democratic decision-making by enabling accountability, rewarding participation and/or anonymity;
- enabling the development of decentralised social networks or clouds, or decentralised platforms for the collaborative economy; and
- managing property, land registry or other public records contributing to financial inclusion.

In addition, DG CNECT, in collaboration with the JRC and with the support of the EP, has launched the **Pilot Project '#DLT4Good: Co-creating a European Ecosystem of DLTs for Social and Public Good'**[24]**.** It is centred on research and experimentation for the development and scale up of DLT solutions suited to specific challenges of public and third-sector organisations at local, regional, national or supranational levels. One of its key activities will be the co-creation of an accelerator programme to stimulate the piloting of DLT-based applications to address existing or emerging sustainability challenges, and ultimately to drive positive change for the common good.

In terms of overall research and innovation (R&I) funding through EU programmes, so far EUR 83 million have been allocated to blockchain-related projects, and potentially up to EUR 340 million could be committed from 2018 to 2020[25].

For instance, the topic of decentralised networks, including blockchain and DLTs, was pioneered by the Collective Awareness Programs for Sustainability and Social Awareness – CAPS programme. Through this and other programmes like Leadership in Enabling and Industrial Technologies (LEIT[26]), projects such as D-Cent[27], DECODE[28] or MyHealthMyData[29] have developed and piloted blockchain and DLTs.

During the Blockchain InfoDay, organised by the EC on 19 December 2017[30], 17 actions related to blockchain and DLTs in the Horizon 2020 Work Programme were presented, encompassing topics associated with SMEs, social good, next-generation internet, smart mobility and living, transport, energy, eGovernment, eHealth, and FinTech. Support for R&I is expected to continue under new EU programmes beginning in 2021, for instance Horizon Europe, InvestEU and Digital Europe programmes.

In the intersection of blockchain with other key industrial technologies, the EC recently announced an equity investment instrument for artificial intelligence (AI) and blockchain, with the aim of making available resources for start-ups and innovators in these areas to help them grow their business. In 2020, EUR 45 million will be provided from Horizon 2020 in order to reach a total of

EUR 100 million for investors across Europe, by leveraging the European Fund for Strategic Investments (EFSI) and the European Investment Fund (EIF) (EC, 2018).

The aim is to focus on financing a portfolio of innovative AI and blockchain companies, developing a dynamic EU-wide investors community, multiplying investments at the national level by involving national promotional banks (NPBs), incentivising private-sector investments, and making Europe more attractive for start-ups to stay and grow here[31].

## 3.4. Exploratory activities

A number of EC services are currently conducting, beginning or reflecting on possible exploratory activities in the field of blockchain and DLTs.

The **European Financial Transparency Gateway (EFTG)**[32] is a pilot project at the initiative of the Directorate-General for Financial Stability, Financial Services and Capital Markets Union (DG FISMA), with funding from the EP. Its objective is to further the EU Capital Markets Union initiative by increasing financial transparency

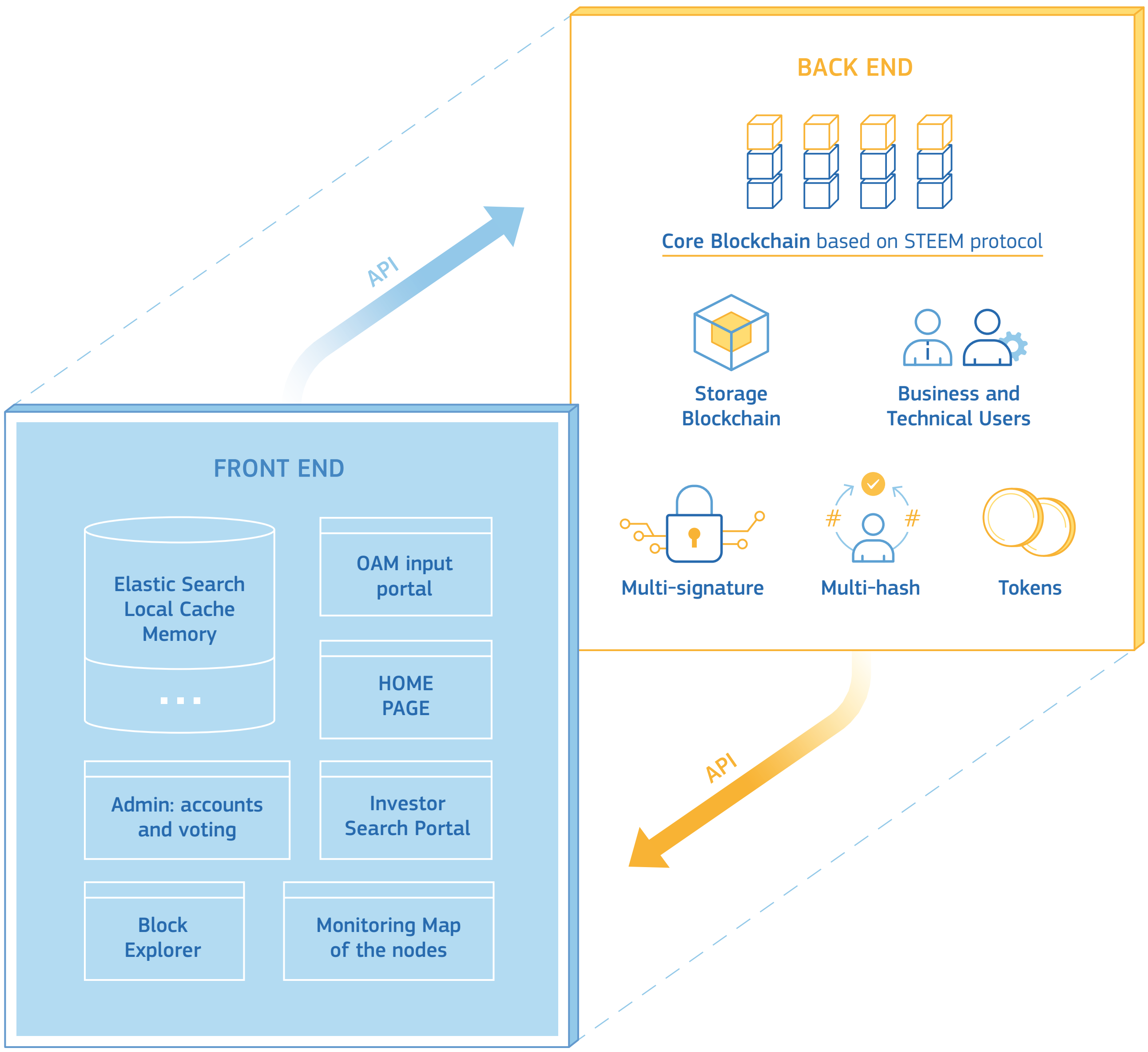



**Figure 12:** EFTG pilot project architecture

and facilitating investors' access to regulated financial information, in line with the Transparency Directive (EP and Council, 2013) and the European Electronic Access Point (EEAP) Regulation (EC, 2016).

The aim of DG FISMA, supported by DG CNECT, was to test how blockchain technology could bring distinct benefits and help to address specific challenges facing this initiative, especially by clarifying concerns related to data control, liability and access rights. In addition, the Directorate-General for Informatics (DG DIGIT) EU Blockchain Competence Centre (formerly DIGIT B4 Blockchain Competence Centre or BLKCC) developed an approach based on DLTs to build a distributed and decentralised platform system tailored to the business needs of officially appointed mechanisms (OAMs) (i.e. Member State entities) in fulfilling the legal obligation to implement an EEAP. The EFTG pilot project architecture is outlined in *Figure 12*.

Unlike classical IT architectures, a blockchain-based solution provides and maintains a secure, reliable link between data and actors in the system while being cheaper and faster to develop and deploy than a custom-built system[33].

In terms of benefits, the platform system facilitates cross-border access to regulated information, thereby lowering the search time and reducing the information access costs while enabling the possibility for OAMs to propose additional value-added data services. Investors thus obtain faster results for the information searched because they no longer have to go through 28 different portals but rather to a single entry point, whilst data ownership is being retained by each OAM.

From DG DIGIT's viewpoint, the EFTG platform offers the following competitive advantages:

- no central data warehouse that would dilute accountability for data quality;
- energy efficiency;
- single framework across the EU;
- data remains owned by and traced back to individual OAMs;
- enables OAMs to offer new services by bringing value to their data;
- solution enables cooperation between OAMs;
- platform system could offer ready-made key performance indicators (KPIs) monitoring tools;

> "The European Financial Transparency Gateway (EFTG) pilot project aims to increase financial transparency *and facilitate investors' access to regulated financial information.*"

- zero-downtime, fault-tolerant as well as distributed denial-of-service (DDoS)-resistant;
- open-source technology[34];
- creates a blockchain in a box[35] which can democratise the blockchain infrastructure across Europe.

To date, eight Member States have actively participated in the pilot, in which OAMs took an active role in running the network by becoming 'witnesses' which are allowed to write blocks as part of the network.

Other exploratory activities, conducted by DG FISMA in the context of a multi-annual ISA[2] action on modern financial data standards, concerned the development of a **RegTech ('regulatory technology') approach** for financial transactions as well as financial risk reporting, which is based on distributed computing and decentralised data management technologies such as DLTs (Kavassalis et al., 2018). This approach would make it possible to generate a 'digital doppelgänger' (digital equivalent) for every financial contract in the form of dynamic transaction documents (DTDs). Such DTDs would automatically make contract data from the transaction counterparties available in semi real-time to relevant authorities mandated by law to request and process such data. They could help reduce compliance costs and ultimately increase the transparency of the global financial system.

> "DG DIGIT's EU Blockchain Competence Centre was set up *to track the evolution of blockchain technology and be ready to leverage its benefits.*"

This approach was leveraged on previous proofs of concept (POCs), including live demonstrators such as the 'report once' **demonstrator for over-the-counter (OTC) derivatives trading** (Sel et al., 2017). This demonstrator made use of Ethereum smart contracts, based on the semantics and algorithmic representations defined in ACTUS (Algorithmic Contract Types Unified Standards) to implement 'digital doppelgängers' of financial contracts. The objective was to reflect the state of traded 'real-world' financial contracts over their life cycle and to allow semi real-time reporting that reflects the status of such instruments at any point during this cycle[36].

In 2017, as mentioned above, **DG DIGIT's EU Blockchain Competence Centre** was set up to track the evolution of blockchain technology, to be ready to leverage some of its benefits, and to provide independent advisory services to other DGs[37].

This centre started with a study conducted by Deloitte called 'Impact of Distributed Ledger Technology in European Policymaking' (IDiLeTech, EP), which attempted to identify classes of the European Commission's core business processes most susceptible to being improved by blockchain and DLTs. The IDiLeTech study focused on three major categories of business processes which appeared as best candidates for a DLT-induced evolution (or revolution): management

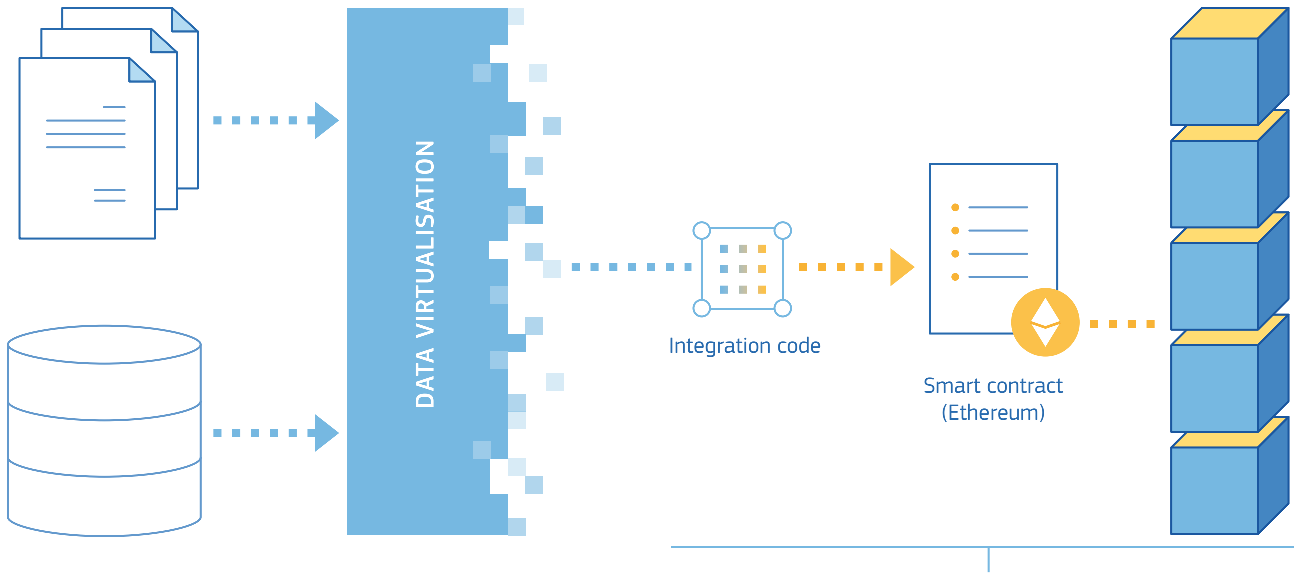



**Figure 13:** DG DIGIT blockchain use case for notarisation

of identities, regulatory processes, and grant processes. The study then identified and analysed several technological platforms showing the most promise in the specific context of the EC, namely Ethereum, Steem and Hyperledger Fabric.

After the study, as one of the first practical use cases, DG DIGIT started working with Luxembourg's Centre des technologies de l'information de l'Etat (CTIE) to build a **private blockchain network (Ethereum PoA) for notarisation** *(Figure 13)*. The situation to be addressed concerned some data records that were being challenged by a third party. If two or more independent legal entities confirm their authenticity through the presence of a hash in a common blockchain system (serving as a 'notarisation engine'), this adds credibility to a confirmation coming exclusively from the challenged entity's IT systems. In addition, this project made use of a newer technology, data virtualisation, to isolate the business logic of the blockchain engine from the physical data sources, thereby increasing its reusability.

In this exploratory use case, blockchain systems can enable extension of the 'trust domain' outside the boundaries of a single organisation. Within efforts to modernise public administration, it can support moving from 'exchanging data' to 'sharing data'. And potentially, it could be the foundation upon which new and better ways of crafting legislation and awarding grants can be built[38].

Internally, within a series of open 'blockchain education' sessions, DG DIGIT has so far run two blockchain boot camps: Session 101 introduced participants to the basics of blockchain, and Session 102 focused on advanced features of blockchain technology (consensus, cryptography and architecture).

In 2017, the Directorate-General for Taxation and Customs Union (DG TAXUD) began exploratory activities to study the potential applicability of blockchain technology in the customs, taxation and excise domains.

The first study and PoC concerns the feasibility of **using blockchain to facilitate and monitor the movement of 'excise goods' in real-time**[39], in particular a permissioned private blockchain based on Hyperledger Fabric. The Excise Movement and Control System (EMCS) is

> DG TAXUD is looking into the potential applicability of blockchain *to facilitate and monitor the movement of 'excise goods' in real-time.*

a trans-European IT system for monitoring the movements of excise goods under duty suspension within the territory of the EU. Among other things, it helps to fight against fiscal fraud, to obtain real-time information about goods being moved, and to have a digital standard procedure for all the economic operators in Europe. However, the high number of operators, exchanges and, in general, the vast amount of information processed by the system makes maintenance of the latter complex and onerous. An opportunity to simplify the processes and to reduce the costs of such a system might be offered by a decentralised system based on blockchain and DLTs, which may allow for an easier exchange of messages and simplified implementation of the business logics. Currently, a blockchain-based prototype of the System for Exchange of Excise Data (SEED), which plays an important role as a registry of economic operators in the EMCS, is being developed with JRC support.

The second PoC focused on the feasibility of a notarisation service whereby a blockchain platform could be used as a third party for holding information generated by supply chain stakeholders . One document of particular interest is the ATA carnet (acronym of the French and English terms 'Admission Temporaire/Temporary Admission'), an international customs document used in 87 countries and territories which mainly enables the duty-free, temporary admission of most goods, usually for up to one year.

In June 2017, a partnership between DG TAXUD and the International Chamber of Commerce World Chambers Federation (ICC WCF) was established whereby DG TAXUD started its PoC to see whether an application based on the blockchain could interface with ICC's Mercury II solution (which replicates the paper ATA carnet) in order to add an extra layer of trust to the process. The paper ATA carnet is replaced by an 'eATA' carnet which is accessible electronically at any time (24/7), and for which the trader only needs the unique eATA carnet reference number to obtain customs clearance. Based on this reference number, the customs offices first receive the data from the partner that issued the eATA carnet, and then registers a transaction.

The PoC  was concluded mid-2018, and has demonstrated that DLT (the Ethereum test network, in this case) could be used to ensure the integrity and traceability of carnets and transactions on a private blockchain platform combined with periodic anchoring on a public blockchain, effectively achieving independent notarisation, as shown in *Figure 14*.

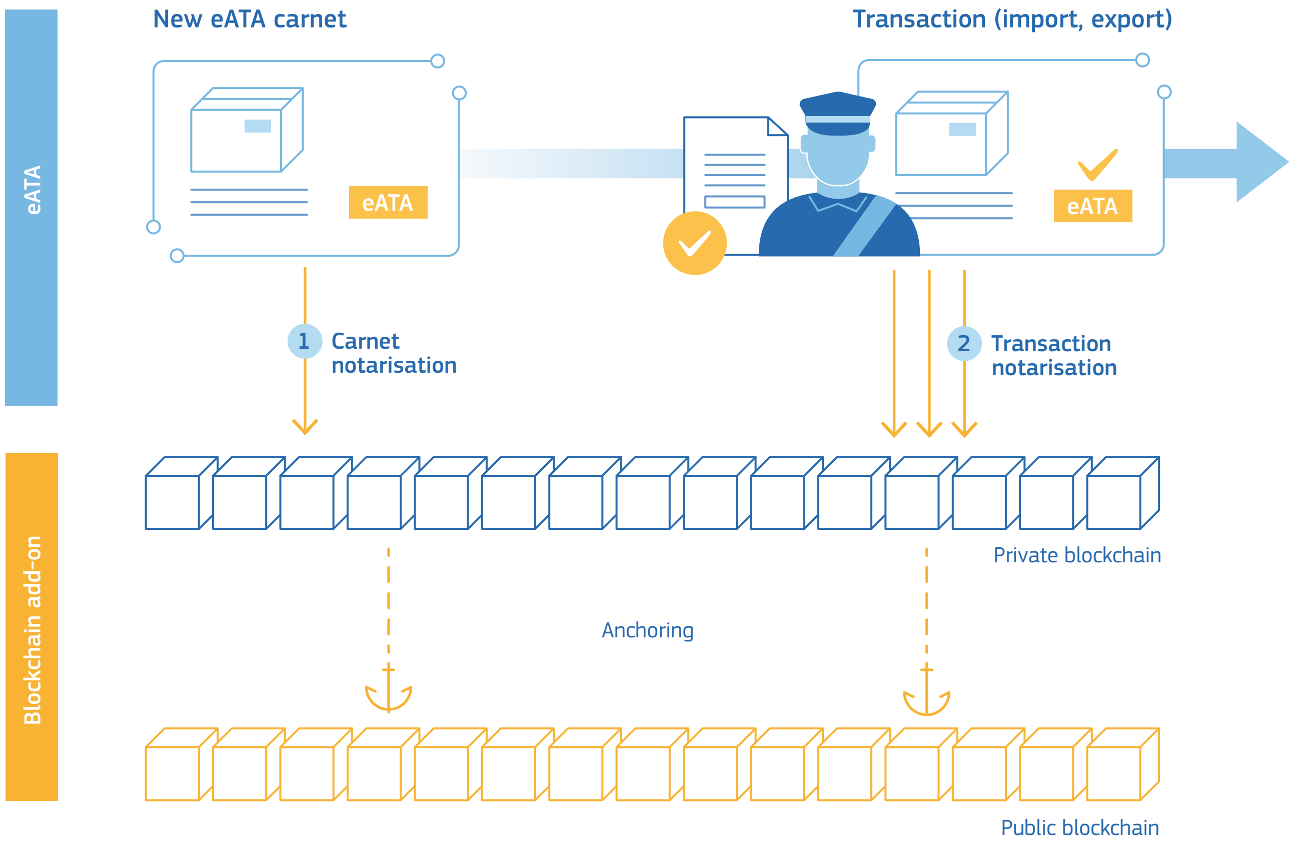



**Figure 14:** DG TAXUD eATA Proof-of-Concept

# PART 3: TRANSFORMATIONS

## SUMMARY

Blockchain applications in finance range from cryptocurrencies and ICOs to financial instruments and payment systems. For instance, ICOs became fund-raising venues for businesses and start-ups in particular as an alternative to formal financing systems. Blockchain could also lower the costs associated with the entire life cycle of a financial instrument by simplifying the process of issuing and reducing clearing and settlement time. Benefits for cross-border payments relate to real-time reporting and update of positions, liquidity management, complete traceability of transactions, and simplified reconciliation across accounts. However, in most cases, the technology is not developed enough to be broadly adopted, or remains limited to small subsets of participants. Regulatory challenges also concern the nature and classification of tokens, consumer and investor protection, enforcement of anti-money laundering requirements, or overall compliance with securities law.

# TRANSFORMING FINANCIAL SYSTEMS

## 4.1. Cryptocurrencies

**Blockchain technology started with the development of Bitcoin,** which was created with the aim of introducing a convenient alternative form of currency not subject to the control of a state authority (Nai Fovino and Steri, 2015; Nai Fovino et al., 2015). It would not need the intermediation of a financial entity to handle payments performed on the internet, and thus would not be subject to the risk of being debased.

Bitcoin is a DLT for the storage of information on the exchange of ownership of a digital representation of value. **In the case of Bitcoin, unlike the so-called 'fiat currency', its value is not supported by the status of legal tender.** Instead, it is solely determined by the trust that each person holding it has in the fact that the underlying technology will not allow double spending, will not be debased, but will be accepted by other economic actors as a means of payment.

The advantages of blockchain have made such a payment system very appealing for several use cases. First, **blockchain-based cryptocurrencies do not need a central authority. This enables users to send transactions and exchange crypto coins simply by creating an account.** This process can be done through intermediaries such as cryptocurrency exchanges and custodian wallet providers.

> Blockchain applications in finance range from cryptocurrencies and Initial Coin Offerings to financial instruments and payment systems.

However, if a person wants to purchase a digital currency from a third party, in some cases she or he will have to register to a trading site which, in turn, will most probably request personal data. It should be noted that, contrary to popular belief, **Bitcoin does not guarantee full anonymity but rather allows for pseudonymity.** It may be possible to associate transactions to the identity of the machines performing them, and it is likely that someone would be in the position to link a cryptocurrency account with its real owner. Yet some cryptocurrencies, such as Monero, explicitly try to guarantee a level of anonymity comparable to that of cash transactions.

Another advantage of cryptocurrencies is that **the transaction is considered verified through the consensus mechanism in place.** Depending on the blockchain implementation, confirmation may be notified within a one-hour time limit, usually even faster. This may be not so evident for the user since online purchases through a credit card usually only take a few seconds. However, it can make a considerable difference for merchants as, in their case, a credit-card payment will only be validated after a few days. Moreover, as the transactions are tamper-resistant, the merchant can be certain that the amount received cannot be withdrawn.

Yet the same feature has its limits when using cryptocurrencies for real-time purchases. For example, when using Bitcoin for purchasing goods from a retail store, the merchant will have to wait for about an hour[42] to be sure that the transaction has gone through. Even with the use of other cryptocurrencies with faster confirmation times, over-the-counter payments are not an ideal use case.

Moreover, **the absence of a monetary authority and a lender of last resort make Bitcoin and most cryptocurrencies highly volatile in the face of speculative activities. It also makes them potentially harder to recover from crises and exposes them to a long-term deflationary dynamic** (Fatas and di Mauro, 2017). This results in them lacking several functions that currencies are normally expected to fulfil, such as being a reliable store of value and a stable account unit.

These limitations have not prevented many other alternative currencies from emerging over the last few years. Nor they have prevented the creation of an entirely new industrial subsector specialising in the 'mining' of bitcoins, which means hosting servers for the storage of blockchains and solving the cryptographic problems which are necessary to validate transactions and add new blocks.

In turn the growing number of competing miners and of currencies has contributed to causing two further issues. The first concerns the creation of network dis-economies, resulting from the proliferation of currencies with a limited circulation and acceptance base. The second issue concerns the increase in transaction costs, due to the nature of the algorithm's underlying structure which, over time, increases the complexity of the cryptographic problems to be solved (Crosby et al., 2016).

We have also witnessed **high growth and volatility when it comes to Bitcoin price and market capitalisation.** Its price grew exponentially until the end of 2017, with two bubble episodes in particular in 2013 and 2017. At the beginning of 2018, it lost around 60 % of its value in a month *(Figure 15).* At its highest level, its market capitalisation reached around USD 320 billion in mid-December 2017 and stood at around USD 100 billion in mid-2018 *(Figure 16).*

> “Absence of monetary authority and lender of last resort *exposes most cryptocurrencies to high volatility in the face of speculative activities.*”


**Figure 15:** Bitcoin/USD exchange rate
**Source:** *Bloomberg*

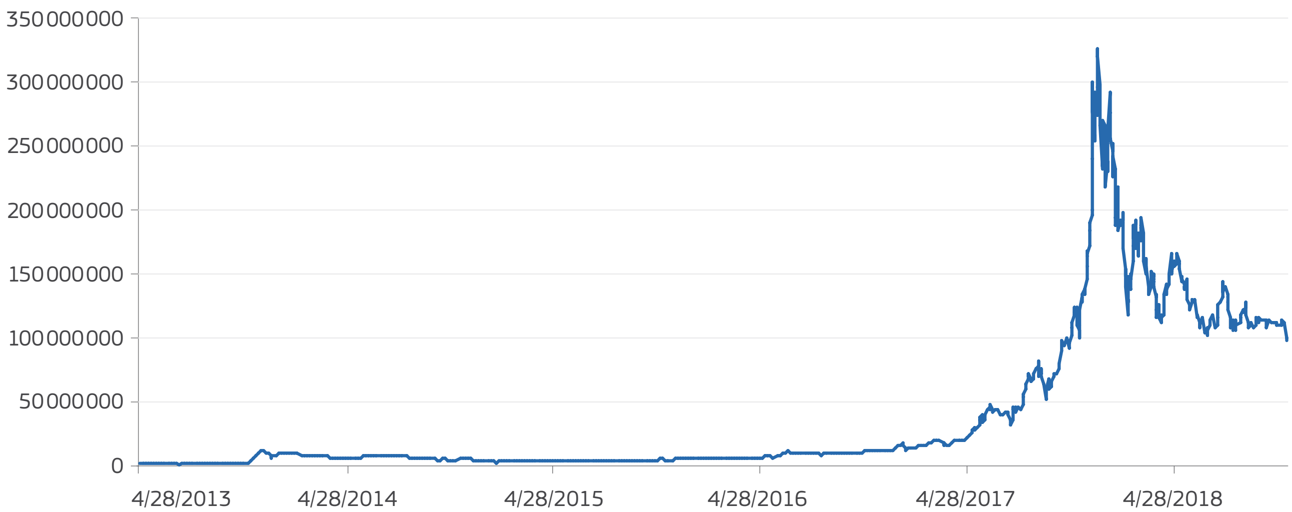



**Figure 16:** Market capitalisation of Bitcoin (USD)
**Source:** *https://coinmarketcap.com*

On the one hand, this excess volatility and long-term deflationary push means that Bitcoin, and many of its current alternatives, should probably be considered somewhat of a failed experiment in terms of reaching their stated purpose of providing a reliable and stable currency.

In particular, **the wide debate continues on the potential use of DLTs and digital tokens as full substitutes for state-backed fiat currencies** (Bech and Garratt, 2017) with most economists demonstrating a very tepid response (Fatas and di Mauro, 2017). Amid suggestions that DLTs and blockchain could perhaps bring significant efficiency gains and general welfare, ECB members have, for instance, dismissed its use to create currency (Reuters, 2018; Mersch, 2018), or more categorically, denounced the inflated hype around them (Bloomberg, 2019).

Nevertheless, a number of regulatory discussions are currently under way. Among clarifications and other measures[43], the 5$^{th}$ Anti-Money Laundering Directive (Directive (EU) 2018/843) encompasses platforms for the exchange of virtual currency to fiat currencies (cryptocurrency exchanges) and providers of electronic wallets for virtual currencies (such as Bitcoin, Ether or Ripple) as obliged actors. That is, they will be required to register with the financial supervisory authorities and to implement measures to counter money laundering and terrorist fund-raising, such as customer due diligence (such as KYC) and transaction monitoring.

On the other hand, the widespread adoption of DLTs and digital tokens and the interest they have generated has provided a test-case demonstration that **blockchains have shown promise in finance for other purposes, such as records of transactions, payment systems and investment products.** Blockchain activity in finance has remained very strong, with the **development of new product classes hybridising cryptocurrencies and DLT-supported fund-raising: ICOs** (see next section).

Moreover, traditional financial intermediaries have shown great interest in the use of DLTs to create investment products and as a supporting technology for trading systems.

The main reasons are that a DLT will be partly or completely decentralised, which may lead to the reduction or elimination of rent positions, and a potential reduction in intermediation costs. Once accepted, transactions on a DLT immediately become visible to all participants, potentially leading to greater reductions in costs, transaction times, and in execution and counter-party risks. As such, in recent years, the development of DLTs in finance has taken two main avenues besides cryptocurrencies and ICOs: the creation of DLT-supported financial liabilities, and the use of DLTs in payment systems.

## 4.2. Tokens and ICOs

The fact that digital tokens could be used to represent not only a means of payment but could also be associated with a generic promise of delivering a payment or any other commodity or service, did not escape operators. It led to the emergence of 'digital tokens' – often referred to by field operators simply as 'tokens' – as a new class of financial products and a new method of financial intermediation.

**Tokens are digital assets used as an exchange medium and normally associated with an underlying blockchain to register these exchanges.** This can be with or without a counterpart: for example, Bitcoin is without a counterpart while Sardex (presented below) has one. It can provide for a relative right, whether it be a service, a commodity or financial rights.

Technically, since tokens are digital assets, they require cryptographic tools to secure the transactions and the ledger. Typically, the technology used is a blockchain. The recent interest in tokens stems from the desire **to find alternative means of funding for businesses and start-ups in particular, and to promote decentralised, mostly unregulated, mediums of exchange** which can be used to support such firms.

Tokens are not something new per se. 'Real' tokens, although not supported by digital technologies, have emerged previously in times of currency debasement or as 'parallel currencies' aiming to support local economies. For instance, the Swiss WIR emerged in 1934 during the Great Depression, promoting cooperative financing at a regional level (WIR Bank, 2015). More recently, in 2010, during the sovereign debt crisis, in Sardinia, Italy, Sardex was introduced with the same goal and eventually transitioned to a blockchain-supported digital token backed by commercial credits (Financial Times, 2015b; Sardex, 2017).

More recently, in search of funding avenues that would not involve the formal banking system, a number of technological start-ups have decided to finance themselves through crowdfunding and by issuing a **new kind of token: ICOs.** These start-ups were soon followed by small businesses looking for more favourable credit conditions (Gordon Mills and McCarthy, 2014; Wehinger, 2014). Recent analyses have underlined, however, that **in their current form ICOs carry important risks for SME issuers and investors subscribing to token offerings.** Such risks arise from the uncertainty of the applicable regulatory framework for ICOs and crypto-asset markets, the lack of financial consumer protection safeguards, and limitations in the structuring of ICOs and operational risks related to DLTs (OECD, 2019).

Our analysis in *section 2.2* shows that important changes have taken place in funding structure and dynamics. As regards the global investment flows in blockchain start-ups across different funding instruments, overall investment exploded in 2017, reaching a total of EUR 3.9 billion, the ICO being the most prominent instrument (EUR 2.6 billion) in the same year. In 2018, significant funding for blockchain start-ups continued to flow via ICOs and venture capital funds which hit EUR 7.4 billion in total. Grants and equity-type funding also rose significantly during that year (EUR 968 million). According to our analysis this indicates that, together with venture capital, there was an obvious shift towards more institutionalised, more professionalised and also more concentrated forms of investor participation and control.

**Nevertheless, ICOs are becoming significant fund-raising solutions** *(see endnote 9).* As observed in *Table 3,* fund-raising through

| 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|
| Company | Amount raised (USD million) | Company | Amount raised (USD million) | Company | Amount raised (USD million) |
| Waves | 16.4 | Hdac | 258.0 | EOS | 4198.0 |
| Iconomi | 10.6 | Filecoin | 257.0 | Telegram ICO | 1700.0 |
| Golem | 1196.0 | Tezos | 1196.0 | Ruby-X | 1196.0 |
| SingularDTV | 7.5 | Sirin Labs | 157.9 | Petro | 735.0 |
| Lisk | 5.7 | Bancor | 153.0 | TaTaTu | 575.0 |
| Digix DAO | 5.5 | Polkadot | 144.6 | Dragon | 420.0 |
| FirstBlood | 5.5 | Qash | 107.3 | Huobi token | 300.0 |
| Synereo | 4.7 | KIK | 98.5 | Bankera | 150.9 |
| Decent | 4.2 | COMSA | 95.4 | Neluns | 136.0 |
| Antshares/ NEO | 3.6 | Status | 90.0 | tZERO (STO) | 134.0 |

**Table 3:** Top 10 ICOs by amount raised, per year and at the ICO closing date. Amounts are valued using the BTC exchange rate at that time (as of 13 November 2018)
**Source:** *www.coinschedule.com*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 0 | 0 | 0.017 | 0 |
| 2014 | 0 | 1.79 | 0 | 0 | 6.00 | 0 | 0.79 | 0 | 20.80 | 0 | 0 | 0.54 |
| 2015 | 0.74 | 0.59 | 0 | 0.95 | 0.54 | 0 | 0 | 0 | 0.73 | 5.30 | 0 | 0 |
| 2016 | 0.30 | 0 | 11.20 | 0 | 19.72 | 0.97 | 2.46 | 12.30 | 11.99 | 12.61 | 22.10 | 5.98 |
| 2017 | 82.01 | 22.46 | 18.86 | 81.82 | 289.72 | 639.05 | 574.79 | 426.96 | 914.86 | 996.28 | 825.60 | 1778.59 |
| 2018 | 2047.15 | 1835.04 | 4251.26 | 1254.53 | 1982.55 | 5798.26 | 839.17 | 1114.96 | 1719.47 | 819.77 | | |

**Table 4:** Amount raised per month and at the ICO closing date. Amounts are valued using the BTC exchange rate at that time (as of 13 November 2018)
**Source:** *www.coinschedule.com*

ICOs is no longer limited to small-time and early financing. Three companies raised over USD 1 billion in 2018 (as of 13 November 2018). The phenomenon took off
in 2017, with the monthly amount raised being multiplied by 100 in just a few months *(Table 4)*.

Such developments might have a positive impact on the economy, taking into account, for instance, the potential role of these solutions in fostering financial inclusiveness, in particular in developing countries (United Nations, 2017).

However, they also raise a number of questions. For instance, are both adequate **assessment of the financial risk involved with tokens and investor protection** in place, as is the case in the banking system.

As mentioned in the previous section, in terms of risk (Guégan and Frunza, 2018), the Bitcoin-USD rate has known two main bubble periods: from November 2013 to January 2014 (+446 %) and from May 2017 to January 2018 (+1 200 %). And from the end of 2017 to August 2018, it lost two-thirds of its value. Its annual volatility is always larger than the risky USD-Russian rouble rate, even during the Donbass crisis. As regards the ICOs, behind the exponential growth in fund-raising, the survival rate for start-ups after 120 days is only 44.2 % (Benedetti and Kostovetsky, 2018), which means investing in tokens is particularly risky.
In terms of investor protection, one issue of particular interest is the level of protection and oversight to which investment in, and emission of, tokens in ICOs are subjected to, and whether this is sufficient or should be modified as the use of ICOs increases. In the 'formal' financial system, such as the banking and investment funds sectors, financial institutions are closely regulated, monitored and audited to ensure their solvency, while financial products are regulated to ensure their transparency and reliability. At the same time, only accredited or qualified investors can hold complex financial instruments to avoid small-time investors exposing themselves to risks they cannot fully understand or control.

In contrast, tokens lack such regulation. Due to the novelty of the phenomenon, **there is no ICO-specific regulation, and the application of existing regulations for other financial products can be complex due to the diversity of tokens and the difficulty of placing them in existing categorisations.** This difficulty is compounded by the global reach of ICOs and the fact that they are often emitted by start-ups which are run by software specialists with little financial background.

This lack of regulation was acknowledged, for instance, when the European Securities and Markets Authority (ESMA) issued warnings regarding ICOs (ESMA, 2017): (i) for subscribers: 'these financing transactions are unregulated, volatile, opaque, unproven in terms of technology and are high-risk investments'; (ii) for issuers: 'tokens are similar to financial instruments, these companies must comply with the applicable rules' (ESMA, 2018a).

However, ESMA stakeholders (the Securities and Markets Stakeholder Group) consider that ICOs and crypto-assets have yet to present obvious stability risks and that ESMA should focus on risks for investors. This view is mirrored by the Financial Stability Board (FSB) (2018) when it states that crypto-assets do not pose a material risk to global financial stability, at least for the time being.

Supervision of ICOs is a key priority for ESMA in 2019 (ESMA, 2018b). According to a recent report by ESMA (2019), its conclusions stress the existence of areas that require the potential interpretation or reconsideration of specific requirements to enable the effective application of existing regulations, and also the absence of applicable financial rules that might leave investors exposed to substantial risks. This is in line with the FinTech Action Plan (EC, 2018) which acknowledges that the rapid price increase and volatility of crypto-assets requires a better understanding of the risks and opportunities that accompany their use and a better understanding of the applicability of EU regulation.

In anticipation of European rules, on 3 October 2018, France passed into legislation an ICO framework, aiming for investor protection but without being restrictive. Outside the EU, on 16 February 2018, the Swiss Financial Market Supervisory Authority (FINMA) published a practical guide on ICOs explaining how it would deal with liability issues regarding these offerings on the basis of the law currently governing financial markets. FINMA defines the minimum information it requires to deal with such requests and the principles it follows to respond to them, thereby bringing transparency to the market players concerned.

> “ICOs are becoming significant fund-raising venues *for businesses and start-ups in particular, as an alternative to formal financing systems.*”

Currently, there are four main regimes in the regulation of ICOs:

- some countries simply ban ICOs (e.g. China, Korea);
- some countries attempt to apply the existing legislation even though it might be difficult to adapt it to the new products and case-by-case adaptations might be needed (e.g. the USA);
- some countries pass progressive legislation (e.g. France, Switzerland); and

- some remain silent, considering either that regulation is premature or that their understanding of the technology and how it applies to the existing laws is insufficient (e.g. Costa Rica).

In general, the dilemma currently facing regulators is whether they should offer protection to consumers, give certainty to emitters, or maintain flexibility in the system to accommodate an evolving technology with possible future economic benefits. On the one hand, complex or poorly adapted regulations have the potential to undermine entrepreneurship (Barseghyan, 2008). On the other hand, it has been shown that some regulation is good for business, providing certainty and enabling trust (Shleifer, 2005; Djankov et al., 2006). Thus, at some point, some regulation and guidance from supervisory authorities might be needed to assist FinTech growth, but it requires some caution to avoid nipping the entrepreneurship growth in the bud (EC, 2018).

## 4.3. DLT - supported financial liabilities

In recent years, some central banks have investigated their own issuance of digital assets. According to recent findings, this could increase GDP by reducing real interest rates, distortionary taxes and monetary transaction costs, and could improve the ability of the central banks to stabilise the business cycle (Barrdear and Kumhof, 2016). Efficiency gains in terms of payments, clearing and settlement could also be traded off by the absence of anonymity (Bech and Garratt, 2017). Of importance is the fact that others have highlighted that this solution in a cashless society would allow for negative interest rates, thereby circumventing the zero-lower-bound issue (Agarwal and Kimball, 2015; Rogoff, 2014; Bordo and Levin, 2017).

While start-ups and enterprises are interested in developing new, dis-intermediated products to raise funding, **incumbent financial intermediaries have also been working on developing their own set of DLT-enabled financial assets.** Their focus is more on combining the technology with more 'traditional' financial products such as loans and bonds.

Generalisation of the tokens may come from the financial institutions which might feel threatened by these outsiders. Banks are currently working on currency-backed digital assets. For instance, UBS is developing its utility settlement coin (UBS, 2016), along with BNY Mellon, Deutsche Bank, ICAP and Santander. Goldman Sachs is also backing a start-up to issue a dollar-backed token (Financial Times, 2015a; New York Times, 2015). Similarly, projects to issue commodity-backed digital assets are emerging (Forbes, 2018; Bloomberg, 2018b), which could potentially enable households to hedge against changes in commodity prices.

**Blockchain technology is promising to lower the costs associated with the entire life cycle of a financial instrument (issuance, trading,**

> "Blockchain technology could lower the costs associated *with the entire life cycle of a financial instrument (issuance, trading, and settlement).*"

**settlement, etc.) and to simplify the process of issuing, while significantly reducing the clearing and settlement time.** For instance, NASDAQ, which is currently experimenting with the use of blockchain technology for trading securities, argues that the time required to complete a transaction could be minimised from the standard T+3 days to 10 minutes, while the settlement risk exposure can be reduced by over 99 % (Nasdaq, 2015). Another significant advantage offered by blockchain technology is the possibility to eliminate the use of physical documents since the interested parties could securely store the assets and the recorded transactions.

The number of companies turning to blockchain technology for easier access to funds (loans and bonds) has increased in recent years *(Box 3)*. Recently, a UK FinTech company issued, cleared, settled and registered the first cryptocurrency denominated bond entirely on a public blockchain infrastructure (Microsoft, 2017). Another innovative aspect of this issuance is that it was fully legally complaint as the Financial Conduct Authority's sandbox had oversight. When it comes to the secondary market, it is believed that one of the first transactions which took place using blockchain technology was executed by an asset management firm that purchased a catastrophe bond, originally issued using blockchain. The company argued that associated transaction costs were significantly reduced when compared to traditional transaction methods (Lombard Odier Invest Managers, 2018).

The unique features of blockchain are attracting the interest of the financial sector – major financial institutions have announced that they are currently experimenting with blockchain technology. For example, 40 of the world's largest banks took part in a broad experiment to test a system for trading fixed-income securities by using various blockchain-technology providers (Reuters, 2016). Other examples include institutions like JPMorgan Chase & Co., in collaboration with the Bank of Canada, which tested a new blockchain platform for issuing bonds. They further expressed their interest in using the technology in order to follow other related processes like origination, settlement and interest-rate payments (JPMorgan, 2018). UBS has also created an innovation lab where similar experiments for blockchain-based bonds are tested. In addition, BNP Paribas is modifying its blockchain platform, used thus far for securities, in order to be able to facilitate private companies in issuing mini bonds (BNP Paribas, 2016).

## BOX 3. World Bank and CBA's bond-I

In August 2018, the World Bank and the Commonwealth Bank of Australia (CBA), the country's largest bank, issued bond-I (Blockchain Operated New Debt Instrument), as the world's first bond to be created, allocated, transferred and managed through its life cycle using DLT (World Bank, 2018). Using a private Ethereum blockchain, the two-year bond raised AUD 110 million (USD 79 million) from seven investors: CBA, First State Super, NSW Treasury Corporation, Northern Trust, QBE, SAFA and the Treasury Corporation of Victoria. In contrast to Bitcoin where transactions take place in an open market, bond-I can be sold and bought among institutional investors who already have access to the platform. The bond is part of the World Bank's broader strategic focus on blockchain and other disruptive technologies. In June 2017, it launched a Blockchain Innovation Lab to understand their impact in areas such as land administration, supply-chain management, health, education, cross-border payments and carbon market trading.

At the moment, blockchain technology is used on an experimental basis for bonds. It is mainly institutional players who can use the platforms (through nodes and/or by invitation only), but the technology could potentially be open to the public and completely eliminate intermediaries. However, potential risks and challenges have to be addressed and agreed at institutional and regulatory levels.

## 4.4. Payment systems

Blockchain and DLTs in general can drive change in the financial services by introducing transparency, simplification and efficiency. The key benefits of these new technologies are related to their ability to create trust in a distributed system, increase efficiency in real-time or near real-time reporting of transactions, and support high resilience. As mentioned in *section 3.1,* on 23 March 2017, the EC launched a public consultation on FinTech (EC, 2017), in which the majority of respondents acknowledged that **DLTs offer significant opportunities in transactions related to payments and securities.**

In this respect, **successful implementations of blockchains in the financial sector are related to payment systems, where the transaction costs can be reduced substantially.** Costs related to retail transactions account, on average, for about 1 % of the annual GDP in European countries (Camera, 2017).

Some case studies on DLT applications relate to cross-border payments, given that the process of transferring money across countries is usually very slow and expensive (Flore, 2018). Successful implementation of blockchain technology in cross-border payments was introduced by Ripple, a US-based FinTech company created in 2012. In April 2018, Banco Santander became the first international bank to provide blockchain cross-border payments using the protocol developed by Ripple; this was followed by many other international financial institutions.

The incumbent company for cross-border transaction, SWIFT – a consortium of more than 11 000 members – responded to this initiative by increasing the speed and efficiency of their system and testing the DLT on a broad scale in a subset of members. The actual settlement system is based on a set of correspondent banks which use the so-called 'Nostro Account', an account held by another bank which acts as a service provider and where the monies are transferred. Between 2017 and 2018, SWIFT carried out an extensive test on the use of DLTs. The results of such PoCs carried out by 34 banks show **effective benefits using real-time blockchain systems, specifically related to real-time reporting and the update of positions, liquidity management, complete traceability of the transactions, and simplified reconciliation across accounts. However, these results also underline that the actual technology is not sufficiently well developed to be broadly adopted and poses significant operational challenges for banks.**

Before the SWIFT test, the first attempt to exploit the potential application of DLT in the financial sector was by the R3 Consortium, established in 2015 by a group of international banks. The consortium now includes more than 200 financial institutions across the world, although not all the technical issues have been overcome, which means that the company and the business have yet to become profitable. Moreover, some prominent original members left the consortium and started to develop internally new processes based on blockchain and DLTs. Also, the big players in the credit-card system began to build blockchain technology for the business-2-business (B2B) sector and for cross-border payments.

Another relevant application of blockchain has been developed by a group of seven banks, aimed at improving domestic and cross-border trade payments specifically for small and medium-sized enterprises (SMEs) in Europe. The 'We.Trade' consortium connects the parties involved (banks and SMEs) on a single platform, using smart contracts to manage the agreements between counterparties and making details of the contracts available in a distributed ledger.

Besides these applications, several major issues impede the broad adoption of DLT in the financial sector in general (Casey et al., 2018):

- Performance and scalability: the current efficiency of blockchain technology is limited since the design of the applications is complex and can introduce bottlenecks due to the latency of the system.
- Privacy: one of the main strengths of DLT is that all pieces of information are shared among participants. However, in financial transactions, this might pose confidentiality issues. Experimental solutions to this issue are linked to cryptography and zero-knowledge proofs.
- Legacy infrastructures: the DLT have to communicate with old infrastructures, the migration of which might be complicated due to the different underlining technology.
- Update and maintenance of the software: since there is no central authority, changing the software requires consensus among participants, which has to be enforced to avoid creating chain splits.
- Real-world applications: the payment cases analysed relate to a small subset of participants. Most of the real use has been around cryptocurrency speculations (Bitcoin).

In 2017, FinTech consultations among the EC participants underlined similar issues. The main challenges highlighted for the implementation of DLT solutions were data standardisation, the interoperability of DLTs, and scalability. The main regulatory challenges raised by DLT were the validity and enforceability of smart contracts; the nature and financial classification

> "Regulatory challenges include consumer and investor protection, *compliance with securities law, or enforcement of anti-money laundering requirements.*"

of tokens; securities law; compliance with General Data Protection Regulation (GDPR); liability rules; governance of DLT networks; and regulators' understanding of the technology.

The consultation also concluded that further analysis is necessary to assess whether or not the current legal framework for financial services is 'technology neutral and able to accommodate FinTech innovation, or whether it needs to be adapted to this end'. It also underlined that financial stability, consumer and investor protection, anti-money laundering requirements and law enforcement must be assured and respected.

## SUMMARY

Blockchain technology can bring a series of benefits to industrial sectors, firms and businesses. These can include the lowering of operational costs, enhancing the safety or efficiency of transactions, proving ownership, origin or authenticity of records, goods and content, avoiding fraud and counterfeiting, or automatically executing contracts. The ways to create value and conduct transactions could also improve through faster, cheaper and more reliable mechanisms enabled by blockchain. However, a number of key challenges lie ahead. It is uncertain how the integration with other digital technologies, such as AI, IoT, and additive or subtractive manufacturing will actually happen, taking into account the cost of migration and interoperability. The feasibility of new business models and the necessary incentives for players to operate in open and decentralised ecosystems must also be tested further.

# TRANSFORMING INDUSTRY, TRADE AND MARKETS

## 5.1. Trade and supply chains

Blockchain enables any type of digital or digitised asset and associated transaction to be recorded, certified and tracked between parties, no matter the physical distance. So, **blockchain-based systems could facilitate 'seamless' and 'frictionless' interactions in global and distributed supply chains between distant and untrusting actors,** including producers, retailers, distributors, transporters, suppliers and consumers.

The technology's features guarantee that a product was processed or distributed by a specific actor at a specific date and time, with little or no chance that anyone could change that record.

Blockchain brings many benefits and challenges to industrial sectors already experimenting with the technology, or soon impacted by its existence.

### BOX 4. Foresight and prototyping for policy

The JRC recently developed the #Blockchain4EU project whereby five speculative prototypes were co-created with multiple stakeholders in the field (Nascimento, Pólvora and Sousa Lourenço, 2018). These fictional learning artefacts were designed to represent in tangible and interactive ways how blockchain and other DLTs may exist in the near future as regards five industrial sectors. The prototypes are meant to stimulate a foresight culture in policy by inspiring anticipatory thinking on opportunities and challenges of a particular emerging technology. They also aim to engage and inform other parties, such as industry or SMEs, already involved with, potentially interested in, or working in areas that may be impacted by blockchain and other DLTs in the short or medium-term. Each material prototype is supported by infographics and videos, and presented with two initial questions aimed at starting a conversation on PESTLE (policy, economic, social, technical, legal and environmental) dimensions.

Several companies are experimenting with the **integration of blockchain technology in mobile phones, smart tags and other IoT devices** to scan QR codes in their products' labels and access information in a blockchain about their origin, production process, quality, expiry dates, lot numbers, and so on.

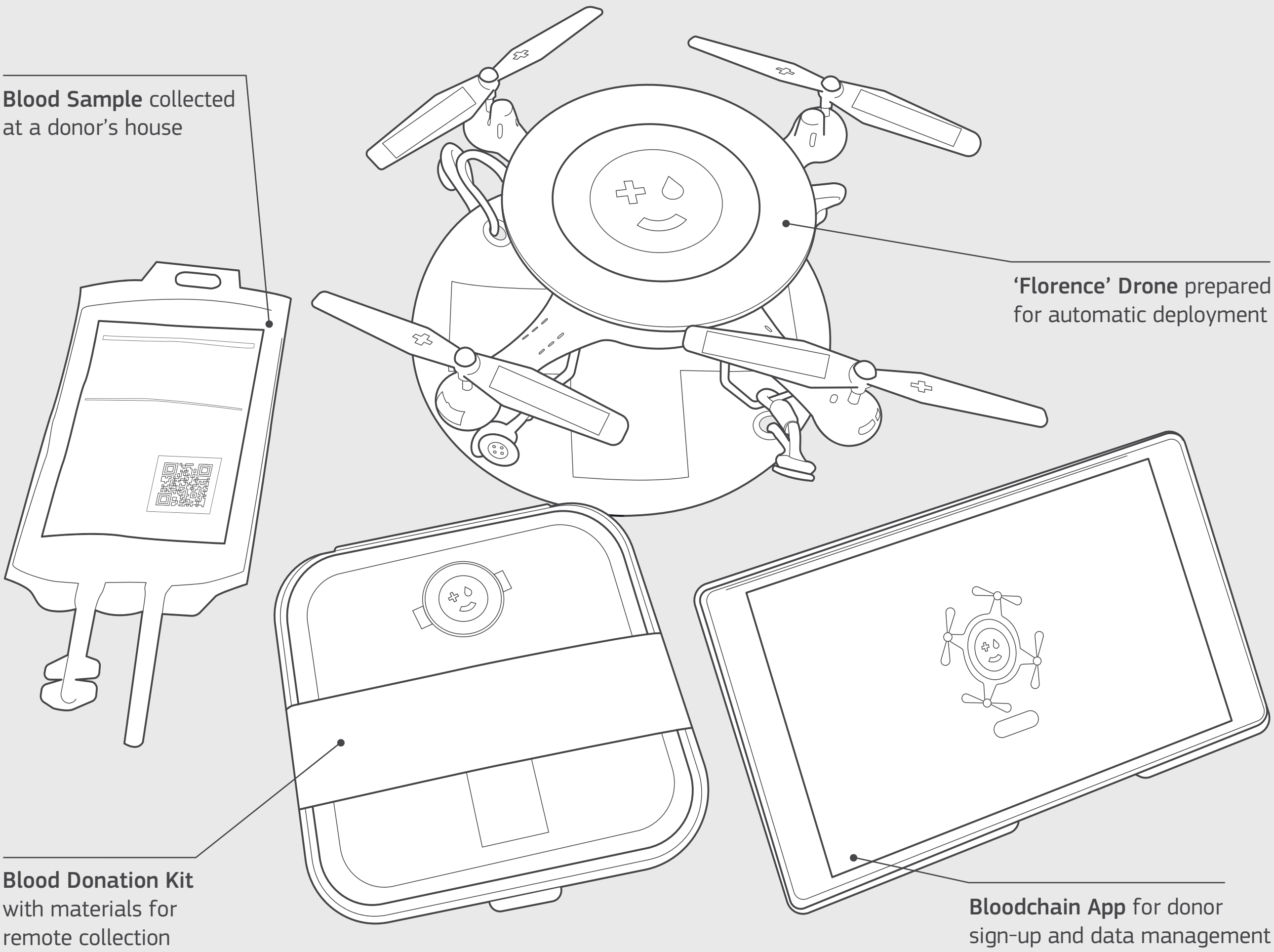
Looking in particular at the transport and logistics sector, blockchain technology could facilitate the **exchange of information between many different actors** (manufacturers, shipping lines, freight forwarders, port and terminal operators, and customs authorities), **for instance about the origin of goods, tariff**

## BOX 5. Bloodchain[44]

What if you could trust a drone to help transport donated blood through an encrypted system? Bloodchain is an assets and fleet management system dealing with multiple supply and demand points for the collection and transport of blood. Its decentralised system streamlines the management, delivery and certification of blood and other sensitive biological materials in automated ways.

**#Blockchain4EU**
**Blockchain for Industrial Transformations**

#Transports&Logistics #SupplyChains #FleetManagement #Tracking #Collection #Encryption #MedicalSpecimen



**codes, classification data, import/export certificates, safety compliance, manifests and loading lists, customs values, or status updates** (Lehmacher, 2017).

For example, documentation to process and verify any cross-border shipping, such as traditional bills of lading about a shipment of any goods could be securely submitted, validated and approved via a blockchain across port authorities, security departments, customs, terminal operators and all other parties involved (Allison, 2016). Coupled with IoT devices, blockchain could enable monitoring the data on containers in ships, planes, trucks

**Front and Back Ends** allow people to securely sign-up as donors and register blood type with an encrypted key. This is connected to a distributed blood bank managing supply and demand in real time.

**Hospital Nodes** get access to donor info and receive notifications if desired blood type and other key data is added. Matching of request and offer depends on compatibility criteria and interests' alignment.

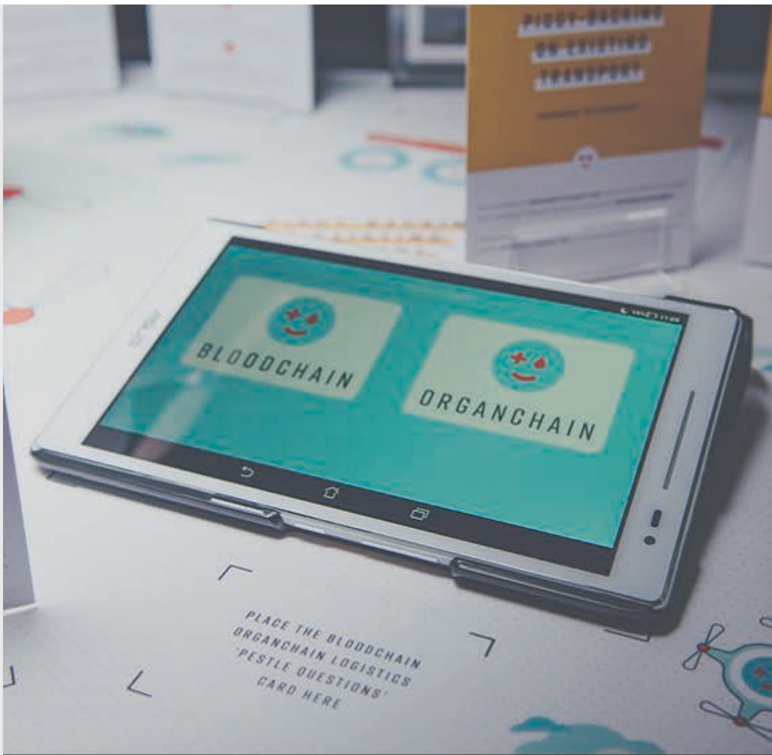
**Autonomous Fleet** dispatches drones to people's homes with materials for remote blood collection. These fly back to hospitals for checks and use, with guarantees of encrypted privacy for donors.

### P E S T L E

**Economic –** How would existing transport systems be affected by new coordination systems which streamline and optimise supply and demand?

**Social –** How could the transport of sensitive materials through autonomous fleets impact people's trust in their collection and delivery?

The co-creation of this prototype was coordinated by the EU Policy Lab of the Joint Research Centre, with the contributions of Cat Drew (Uscreates), Robbie Bates (Uscreates), Travin Keith (Agavon & Member Representative Hyperledge), Mika Lammi (Kouvola Innovation) and Marcella Atzori (University College of London).




or other transport, regarding, for instance, the characteristics of the load, location, shipping conditions such as humidity and temperature, or specific instructions.

A PoC in this type of application is the SmartLog project which is currently developing a blockchain solution for operational data-transfer traffic in the logistics industry. Funded through the Interreg Central Baltic programme, the project is led by Kouvola Innovation Oy with partners Region Örebro County in Sweden, Latvia's Transport and Telecommunication Institute, Valga County Development Agency from Estonia, Sensei LCC from Estonia, Tallinn University of Technology in Estonia, and IBM. Their goal is to reduce end-to-end cargo transit times along two TEN-T core network corridors in the Baltics, namely the ScanMed and the North Sea-Baltic. IoT devices are attached to shipping containers to keep track of actual movements and added to a blockchain system, in this case based on Hyperledger. This secure and unique record is shared between all participating companies along the supply chain, with the goal of improving operational flows, resource management and route-optimisation planning. In the future, data could flow seamlessly between the companies' operational information management systems using blockchain systems, within a transparent and encrypted multi-party transaction ecosystem.

Another application concerns inventory and supply-chain finance, especially in countries where SMEs are the main players operating warehouses, delivering containers with trucks, barges or trains, and/or providing customs-clearance services (Beije and Jullens, 2016). For instance, in a post shipment scenario, a consignment note for a delivered cargo could be made available in a blockchain system, triggering payment of the invoice based on a smart contract. Or for in-transit financing scenarios, information about the inventory at a logistics service provider could be readily accessible to financing parties, which could then provide credit more quickly to SMEs or increase the percentage of the financed inventory. This could potentially stimulate more agile business models between financial institutions, logistics providers, shippers and receivers, all working in the same ecosystem.

Still in the transport sector, the JRC has developed the Ridechain project as a PoC in the applicability and market potential of blockchain technology for asset sharing in road transport (Tsoniotis et al., 2019). First, market research and analysis were conducted to support the development of a new service concept and business model for blockchain-powered shared mobility. Specifically, this research resulted in the definition of a technology platform that leverages blockchain, cloud services, and in-car technology to enhance trust, streamline coordination, and improve information exchange in peer-to-peer (P2P) car-sharing ecosystems. Next, a prototype was developed to demonstrate the technical feasibility of the novel service concept using state-of-the-art blockchain and IoT frameworks.

Now looking into applications for food distributors and retailers, **blockchain-based systems could provide an accurate and updated record of products along their production, shipment and sales helping, for example, in the case of outbreaks to determine more quickly and precisely the points of contamination** (Aitken, 2017). It could also enhance efficiency for real-time management of food stocks and delivery, and help to identify where and why food is thrown out or has expired, thereby potentially reducing food waste.

**Traceability and quality control as regards how products are grown, stored, inspected and transported – that is, from the farm to fork** – could enhance accountability for all involved, including suppliers, regulators and consumers. In a blockchain system, everyone has access to and a copy of the same updated record, so relevant parties can verify or inspect it at any time or at specific moments. This confers a certain level of trust about transactions between distant

> Traceability and quality control as regards how products *are grown, stored, inspected and transported could enhance accountability.*

and often unknown parties in global food chains. Such resilient and shared asset registries could also be used by customs authorities, rights holders and logistics operators for more effective decision-making and faster actions against infringements, counterfeits, stolen and parallel-imported goods[45]. Blockchain could facilitate anti-counterfeiting and the enforcement of IP rights by showing everyone in the supply chain who owns what and who is an authorised licensee, making it possible to validate a genuine product as well as distinguishing fake ones. A distributed ledger holding IP rights information would allow for provenance authentication as the ledger can record objectively verifiable details about origin, timing and production of goods. This would have the benefit of giving businesses, authorities and citizens both confidence and reassurance.
For example, one use for fighting counterfeits is the addition to products of scannable blockchain-connected tags, tamper-resistant seals or imprints. Brand owners can then inform customs authorities about the correct security features genuine products should have, which would allow border officials to easily check whether a product has these features, thereby assessing if it is counterfeit. In a similar manner, this technique could be used for certification marks, certifying that products meet specific preset standards or criteria (Clark, 2018). For instance, take high-value, rare and luxury goods such as protected designations of origin (POD) or wine[46]. Authenticity and provenance of a particular bottle of wine, for example, could exist in a blockchain through a registry of its unique 'thumbprint' comprising high-resolution photographs, ownership and storage records and even a certification for the actual bottle.

Blockchain-based systems offer an irrevocable, authenticated and time-stamped history of products for keeping track not only of product safety and authenticity, but also of ethical standards. **Proof of origin and compliance with environmental rules, organic labelling, fair trade or other such characteristics could help consumers to make informed decisions, and steer companies towards more sustainable business models** (Steiner, 2015).

Safeguarding the accuracy of product certificates and preventing risks of fraud and adulteration could be supported by a trusted registration of product attributes and transactions, together with the easy transfer of import and export certificates. It could be the basis for **more open ecosystems of producers, growers, traders, logistics companies, product standard organisations or certification-scheme owners, data/information standard organisations, ICT services and solution providers, certification organisations, supervisory authorities such as accreditation authorities and food safety authorities, financial service providers such as banks and investors, and consumers** (Ge et al., 2017). This could be particularly useful for smaller farmers and cooperatives if it could facilitate digital certification, direct information flows and marketing to consumers, or even automate a number of transactions and procedures using smart contracts with other stakeholders such as distributors and retailers.

## 5.2. Smart manufacturing

Blockchain may support the use of digital data in manufacturing processes in close integration with other digital technologies such as IoT, AI, robotics, or additive or subtractive manufacturing. As a tamper-resistant digital record, a blockchain could register

### BOX 6. Vantage Point

What if you could access all the information you need before repairing a second-hand scooter? Vantage Point is a platform tackling data sharing, interoperability and integrity in manufacturing by storing, managing and allowing access to digital twins of specific products, parts or materials. This enables different actors in multi-stakeholder chains to access certified information based on their specific needs and permission rights.

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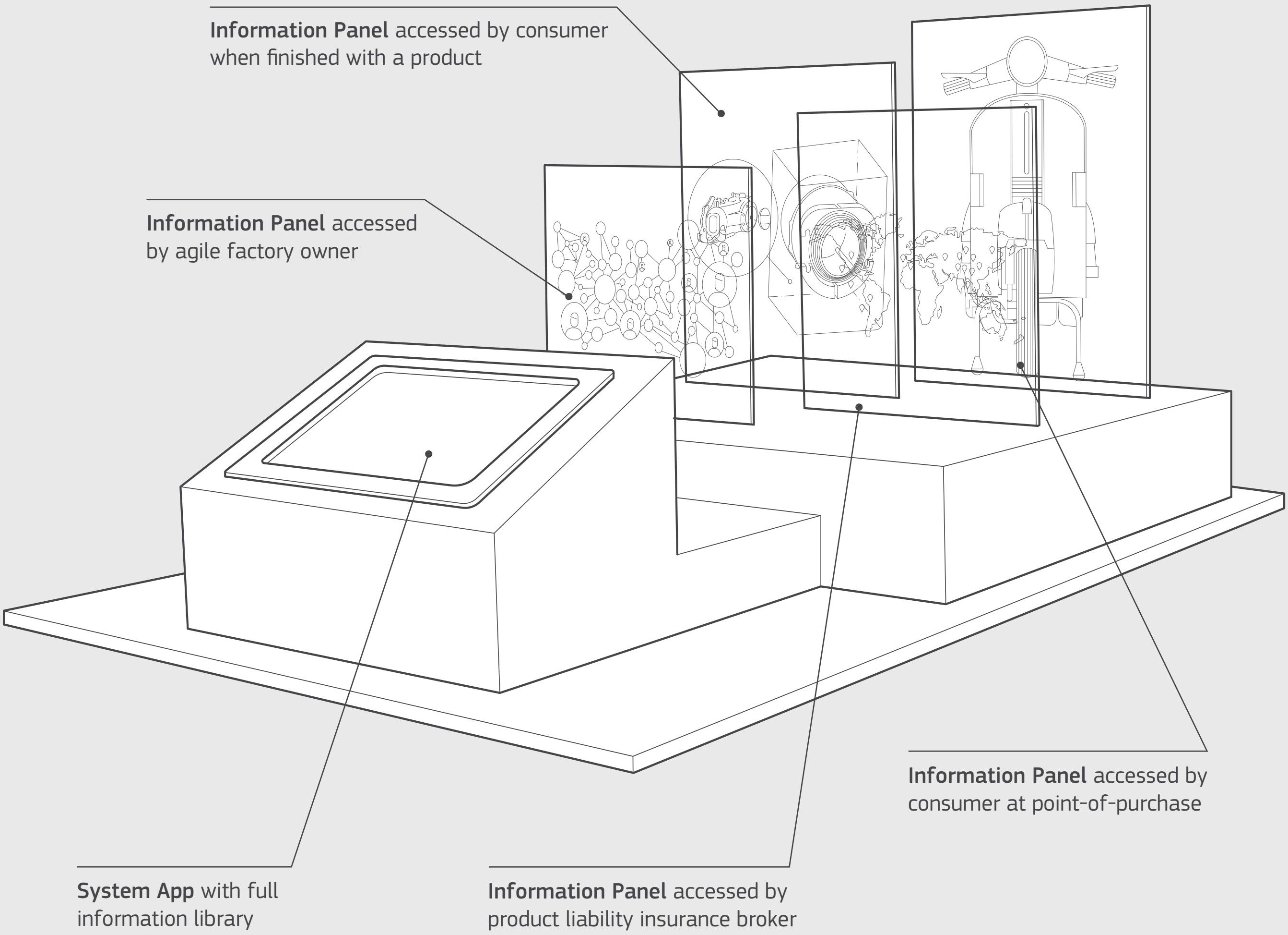
Blockchain for Industrial Transformations

#AdvancedManufacturing #MaterialsLibrary #DigitalTwins #SupplyChains #Interoperability #InformationIntegrity #AgileFactories



the set of characteristics associated with a product, such as physical qualities, design specifications, materials used, ownership, place of manufacture, maintenance history, certifications or warranties. If the products are monitored via IoT devices or sensors along the whole process, a blockchain could also register information on location, availability or status. This record would support the digital representation of any physical or digital product – that is, in a sense, a 'digital twin' or digital product memory encompassing all relevant data to be accessed and used through the whole chain (Stocker, 2017). Any changes to the product made by the parties involved would be added, time-stamped

**Digital Twins** of consumer products are created with full history from cradle to cradle. These twins are then stored on blockchains to ensure authenticity, validity and interoperability of information.

**Tracking and Tracing** of materials and processes is made possible at every point of the supply chain. Information integrity is guaranteed through combined, immutable, real-time data through a decentralised database.

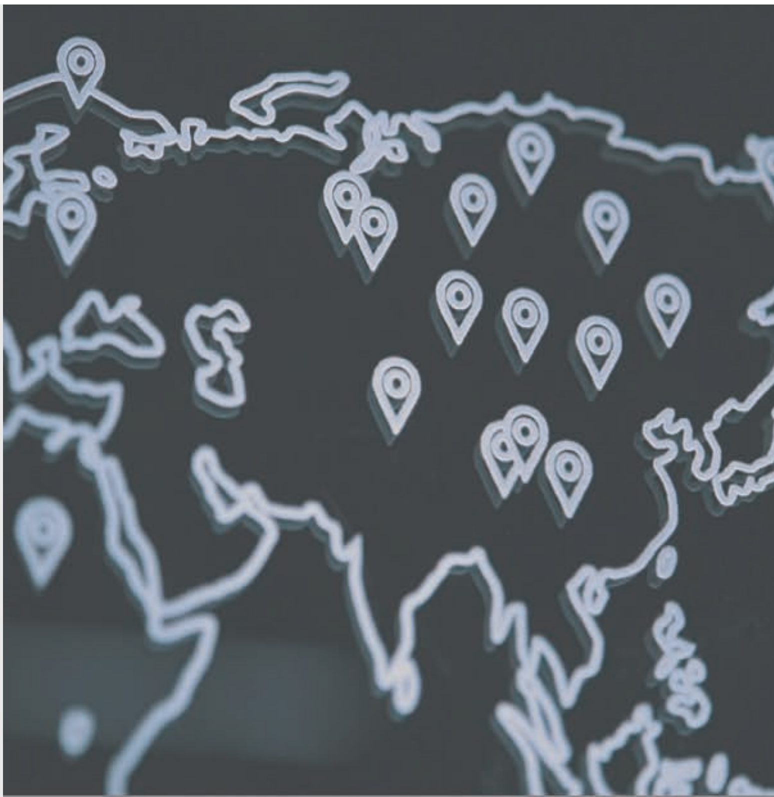
**Multiple Actors** in the same chain get access to distinct information sets. These sets are adapted to their needs, based on the use of private key cryptography linked to distinct agent profiles and permissions.

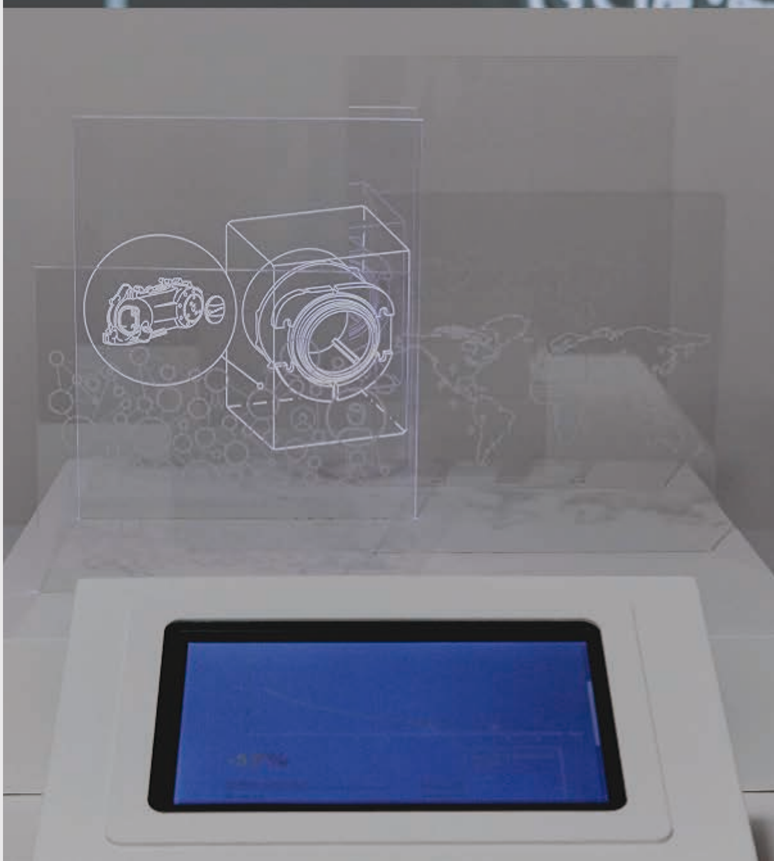
P E S **T** L **E**

**Technological –** How could complementary data management platforms help to ensure accurancy and validity of original information?

**Environmental –** How would distributed forms of data sharing support adoption of cradle-to-cradle systems in manufacturing chains?

The co-creation of this prototype was coordinated by the EU Policy Lab of the Joint Research Centre, with the contributions of Liz Corbin (Institute of Making, University College of London), James Tooze (Royal College of Art), Pierre-Alexis Ciavaldini (Particl Foundation), Wessel Reijers (Dublin City University) and Romain Meunier (Institute of Making, University College of London).





> Blockchain may support the use of digital data *in close integration with other digital technologies such as IoT, AI, robotics, or additive or subtractive manufacturing.*

and tracked on a blockchain. This updated record would be available to everyone, regardless of their location, with the proper or necessary identity credentials. **Blockchain would store the digital identity of each manufactured part via embedded serials and identifiers, and provide, for instance, proof of compliance with mandatory warranties, licences and standards in their production, installation and maintenance.**

Blockchain's decentralised feature could also be useful in production scenarios using additive manufacturing or 3D printing. Digital files could be easily transmitted across a number of parties and geographical sites, from the original designers to a factory's production floors. Its cryptographic mechanisms would also guarantee authentication of such files. Overall, **blockchain could serve as the backbone and security layer for digital data flows for the design, modelling, production, validation, use and monitoring of 3D manufactured parts** (Deloitte, 2016b).

Digital supply chain solutions for 3D printing are being tested within the trends of Industry 4.0[48]. Blockchain could support more lean manufacturing processes based on point-of-use and time-of-need supply chains – that is, on the availability of parts when and where they are needed. A company could purchase a digital file and use a blockchain to transfer the file and also to verify the 3D printing vendor and printing machines which are closer to the final place of production or assembly. Transactions, including orders and payments between companies, are automatically executed and completed through smart contracts which also maintain logs of an asset's authorised uses (Dieterich et al., 2017).

In the future, smart contracts could eventually locate the most appropriate production facilities and negotiate the terms autonomously based on availability, price, quality, delivery or location. Such processes are expected not only to save inventory, import and logistic costs, but should also lead to a reduction in ecological footprints and ultimately boost self-sufficient local economies.

Take the case of the Genesis of Things project. It is developing an open secure platform to decentralise industrial manufacturing, with the aim of reducing inventory costs and lead times, increasing production efficiency and improving product life-cycle management. The proposed model would allow for companies to scan and/or access 3D designs of spare parts, for example, securely their transfer and to produce them on demand in 3D printers at locations close to their operation and maintenance centres. Smart contracts could eventually be used to select, track and automate any type of transaction, including access permission, logistics procedures, associated rights and execution of payments. In a PoC or demonstrator for a blockchain-based shared 3D printing factory, some of the companies involved (Cognizant, innogy and EOS GmbH Electro Optical Systems) tested end-to-end encryption of 3D print files to produce titanium cufflinks with a unique ID and digital product memory (from their creation to their transmission and fabrication via a 3D printer).

In more future-oriented scenarios, blockchain could eventually usher profound changes in manufacturing processes towards decentralised and autonomous smart production (Blechschmidt and Stöcker, 2016). For instance, **such technologies may create more trusted and flexible relationships between manufacturers, suppliers and customers in a context of open and digitalised ecosystems, particularly for niche players such as micro-factories or small service providers.** It would be a mainly **data-driven ecosystem as the basis for potential new business models,** which could be able to leverage available real-time data about source raw materials, best manufacturers, characteristics and location of products, and/or quality controls and assurances (Cognizant, 2018).

Within scenarios of additive and subtractive manufacturing, **blockchain could also serve as a tamper-resistant record of digital files ownership, and in the end could help to prevent unauthorised use, thefts and infringements.** It could improve IP management processes such as patents, trademarks or design rights, along a long, distributed network of creators, providers, sellers, manufacturers and distributors. Blockchain technology has the possibility to provide an indisputable record of registered IP, whether they are patents or trademarks. In this case, the use of blockchain could expedite the process of registration without necessarily relying on existing central bodies or offices.

'Hashing' and 'proof of existence' features can be particularly beneficial for the patent system. First, hashing is the process of transforming a document into a fixed length code, known as a digital fingerprint or hash. The hash has the characteristic of being unique and impossible to regenerate as a document. Secondly, 'proof of existence' involves recording hashes on a distributed ledger, which means a record is created showing that a hash existed at a certain time. The fact that a document existed could be publicly recorded without revealing its content. Thus, **developing blockchain technology within the patent system could reduce inefficiencies in both recording and settling the registration time.** Potentially, there is an opportunity to deploy this technology across several national patent systems (Boucher et al., 2017).

Another application could be the registering and tracking of IP certificates, which could help academic institutions, research journals or other

> "Blockchain may create trusted and flexible relationships *between manufacturers, suppliers and customers in open and digitalised ecosystems.*"

actors to manage various types of IP. For example, patent offices could certify the first inventor of an invention and award them monopoly of the specific market and profit from their invention for a number of years (Inamorato dos Santos, 2017).

## 5.3. Energy systems

Leveraging its feature of decentralisation, blockchain could offer alternatives to long-standing inefficiencies, vulnerabilities and losses of centralised solutions, relying mainly on mass-production energy infrastructure. Blockchain allows multiple

### BOX 7. Gigbliss[49]

What if your hairdryer could save you money by trading energy with power grids or even other hairdryers? Gigbliss is an IoT suite that offers three models of the same hairdryer, AUTO, BALANCE and PLUS. These appliances allow for and represent distinct economic models of automated energy consumption, management and trading.

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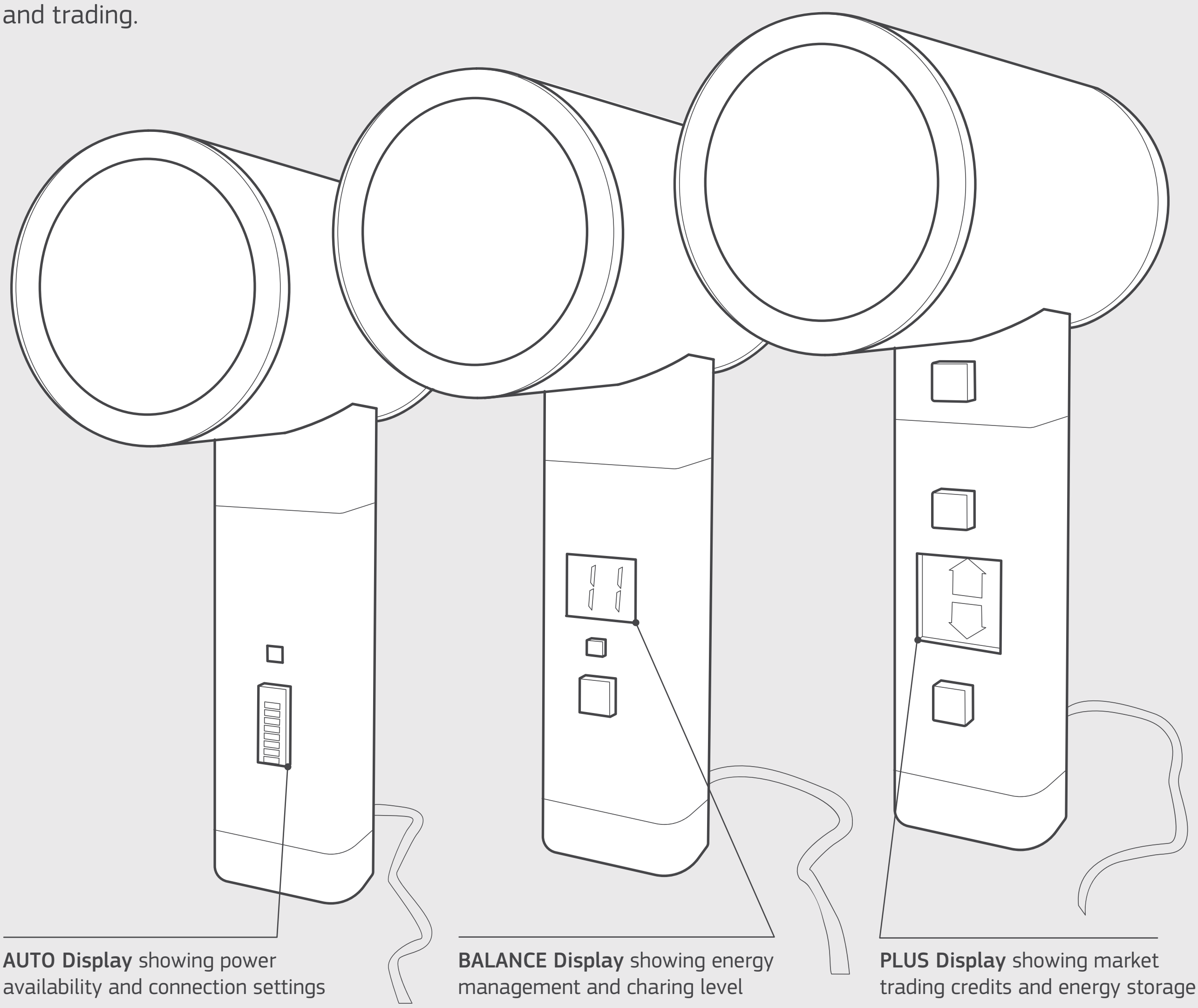
#Energy #IoT #Consumption
#Trading #SmartStorage
#SmartContract #SmartGrids



**AUTO Display** showing power availability and connection settings

**BALANCE Display** showing energy management and charing level

**PLUS Display** showing market trading credits and energy storage parties to coordinate among themselves and execute transactions in an open and transparent way, with differences remaining according to the type of public or private architectures chosen.

Many are seeing it as a data-coordination and management infrastructure that could boost the emergence of a decentralised energy transaction and supply system (PwC, 2016b). For instance, co-founded by the Rocky Mountain Institute and Grid Singularity and with a network of nearly 50 affiliates, Energy Web Foundation (EWF) is developing an open-source and scalable blockchain platform as a digital infrastructure

**AUTO Model** is offered for free but works only automatically at off-peak times. It is linked to a smart contract that enables users to dry their hair without costs until their allocated time period ends.

**BALANCE Model** lets consumers use it when energy prices are marked low. A smart contract manages it and minimises energy costs by automating trade of stored energy when the hairdryer is not in use.

**PLUS Model** allows usage on low energy costs all times, automatically finding the best energy deals for the user. It also monetises itself by letting users buy and sell energy, or negotiating directly with the grid.

**P E S T L E**

**Policy –** How would regulation respond to IoT products which balance energy costs and demand in distributed ways rather than centrally?

**Environmental –** How could smart energy management models create new or more efficient pathways for responsible consumption?

The co-creation of this prototype was coordinated by the EU Policy Lab of the Joint Research Centre, with the contributions of Chris Speed (University of Edinburgh), Larissa Pschetz (University of Edinburgh), Marco Sachy (Dyne.org), Michael Rüther (Spherity GmbH), Juri Mattila (ETLA / Research Institute of the Finnish Economy), Rory Gianny (University of Edinburgh), Katherine Snow (Povo design) and Linda Ma (Povo design).


designed for the energy sector's regulatory, operational and market specificities. EWF affiliates can build proprietary applications on top of the EWF's open-source blockchain as a foundation base layer, under a framework licence agreement between EWF and Parity Technologies. In its current configuration, this platform is based on a decentralised PoA consensus mechanism with permissioned industry validators and a combination of on- and off-chain governance. Affiliates are testing it in use cases such as transactive energy, microgrids, community solar, renewable energy procurement and trading, electric vehicle charging, and demand response. EWF is also developing several open-source solutions such as 'EW Origin' which records information including location, time, source type and CO2 emissions and automatically tracks the ownership of renewably generated electricity.

"Blockchain could offer decentralised alternatives to l*ong-standing inefficiencies, vulnerabilities and losses of mass-production energy solutions.*"

An application of blockchain in the energy sector concerns the use of smart contracts to automatically manage supply-and-demand flows in near real-time and towards an optimal use of available energy (Mattila et al., 2016; Hukkinen et al., 2017). When such smart contracts are embedded in other technologies, like smart meters, smart devices and/or sensors, peer-to-peer trading scenarios could be foreseen. Appliances, batteries, power plants or any point on the grid could sell and buy energy constantly and automatically towards a balancing of the market. Several companies are testing out blockchain-based trading platforms for power, natural gas and others that could connect large producers and factories, retailers and eventually households (Bloomberg, 2018a).

## 5.4. Digital content

As a database or ledger, a blockchain can store a transparent and tamper-resistant record of all data exchanges in a multi-party ecosystem. From here comes the possibility of creating a **shared database to register ownership rights, licensing terms and royalty rules, globally accessible and potentially validated by all parties** depending on the type of consensus mechanisms in place. This could provide tamper-resistant evidence of ownership for the cataloguing and storing of original works, which would present great benefits in providing clarity to copyright authors, owners and users. This means third parties would be able to use the blockchain to see the complete chain of ownership of a piece of work.

By authors registering their work, a digital certificate of authenticity would be created that could facilitate third parties identifying authors of works, while enabling authors and owners to tackle infringements and get more value from what they create (Shinner, 2017). That is, a tamper-resistant register of all sales, licences, loans, donations and other transfers of original works would **help authors or artists to track when and who is using their work and to specify royalty fees.**

> A shared database to register ownership rights, licensing terms and royalty rules, *globally accessible and potentially validated by all parties.*

In addition to protecting the rights of the original creators of digital work, who may retain some rights after selling their content, blockchain technology could also protect consumer rights associated with digital products. This could apply to both mass-reproduced works equivalent to CDs and books as well as to the emerging field of unique digital artworks, which can be considered the digital equivalent of paintings (Boucher et al., 2017). **Consumers or buyers could also more easily verify the real owner of the content, the type of version, the set of rights attached to it, and agree to the terms set by the rights holders.**

Organisations and entities involved in the music and media business, like record labels, publishers, performing rights societies, streaming services, managers, artists and start-ups, could benefit from such a record to counter lost or misdirected rights revenues. Blockchain could be the technological basis of such a concerted effort[50], despite previous unsuccessful attempts to build single online copyright and information portals for musical works (Milosic, 2015).

In this area, for instance, Ujo Music is a music software services company developing an Ethereum-based platform that allows musicians to automatically licence and sell their work using smart contracts and associated cryptocurrencies. A piece of music is inserted and published publicly in the ledger as belonging to the artist, and including licensing terms to enable consumers or buyers to compensate the artist according to the terms set out in smart contracts. For example, as a first demonstrator they worked with Imogen Heap in 2016 to release the track 'Tiny Human' through a direct fan-to-artist payment scheme. In the future, it could be possible for artists and consumers to have portable digital identities running on a blockchain but interoperable with streaming services like SoundCloud, YouTube and other online music services. By digitising and authenticating rights and metadata and making them accessible, such open ecosystems could reduce the entry barriers for new artists, simplify licensing and rights management, facilitate immediate payments to owners and creators, and enable new applications, products and services with minimal friction and more balanced distribution or sharing of the work[51].

The wide deployment of blockchain systems in creative industries could help **prevent infringements or unauthorised use, and overall enable more efficient, cost-effective and potentially fairer ways to compensate the owners and creators through pay-per-usage, micropayments or automatic payment distributions.** Smart contracts could be useful in assisting in the sale and licensing of IP. For instance, they could track if a particular composition is owned by specific parties, such as writers, publishers or artists, check the use or streaming of this composition, then automatically execute how the revenue is divided by the copyright owner or owners, and eventually distributing the payments seamlessly.

Smart contracts have the potential to enable self-executing licensing upon use of a work (Shinner, 2017). The combination of blockchain technology, IP and smart contracts could also access content that can be lent to others for fixed periods before automatic return. In addition, inheritance claims could be

## BOX 8. Gossip Chain[52]

What if you could register, validate and use gossip as valuable information in your own neighbourhood? Gossip Chain is a system allowing anyone to submit rumours and other stories to a localised Blockchain. The structure in place combines people's reputations and prediction markets to assess and register the information's value and reliability for common goals.

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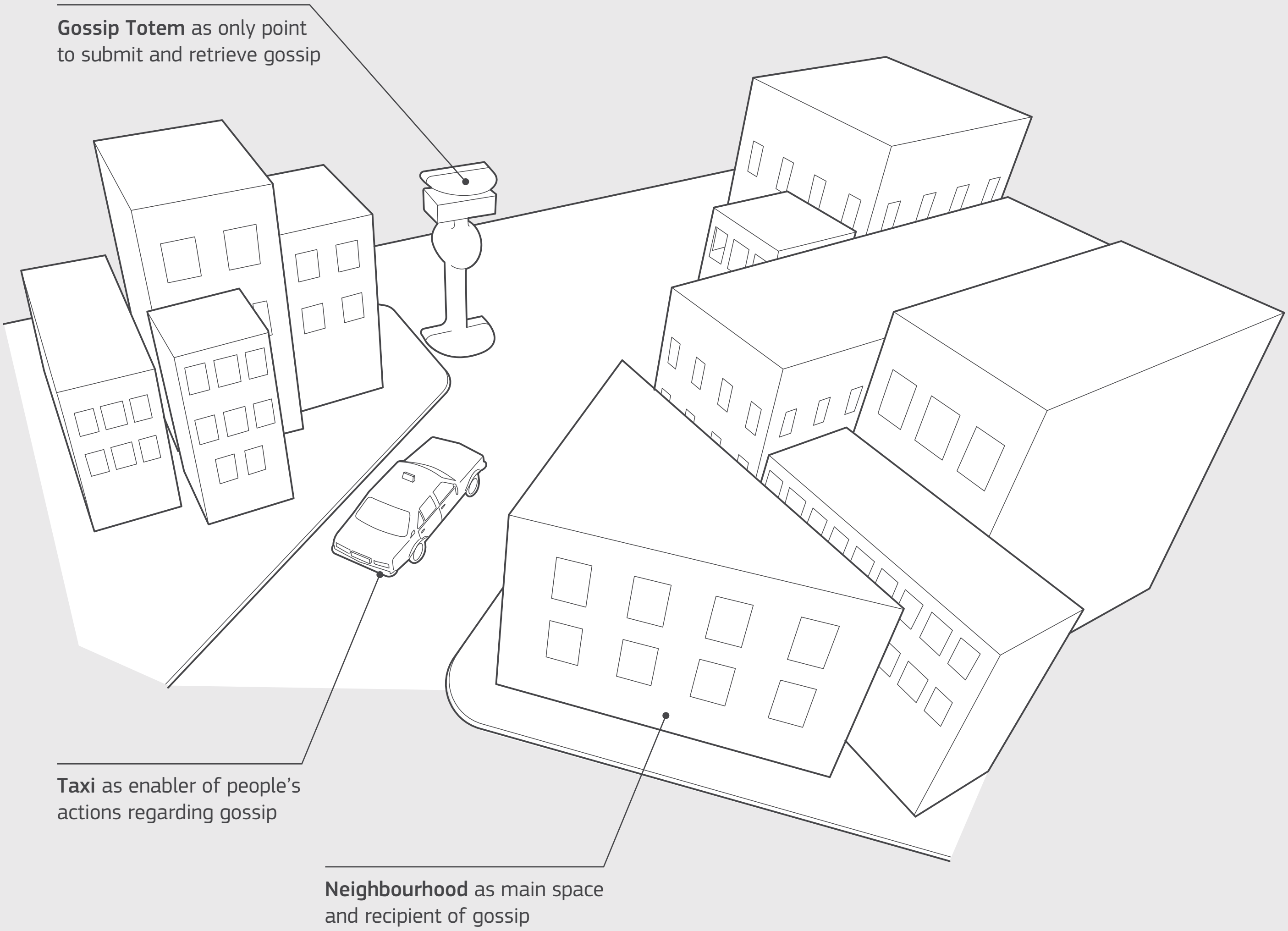
#CreativeIndustries #IntellectualProperty #InformationValidation #PredictionMarkets #Reliability #Reputation #DigitalGoods



implemented automatically upon registration of a death certificate (Boucher et al., 2017).

The idea of smart contracts and smart licensing of proprietary material, such as software, music and digital art, is that contractual control of transactions between two or more entities can be confirmed programmatically through the blockchain rather than through a central gatekeeper or arbitrator. Thus, smart contracts have the benefit of eliminating the need for two parties to depend on a central authority because they can agree between themselves and define the terms and implications of their agreement

**New Rumors** can only be submitted and retrieved at a Gossip Totem physically localised in the neighbourhood. A Gossip Wallet then allows everyone to participate and receive rewards through prediction markets.

**Information Reliability** is assessed based on the reputation of the person that submits the content. This in turn depends on market demand for wtheir gossip, and other people vouching for them and the content itself.

**Verifying Gossip** guarantees financial rewards via smart contract attached to the Gossip Wallet. But financial sanctions also exist if enough evidence is added to contradict the information originally provided.

P E **S** T **L** E

**Social –** How could decentralised mechanisms for validation and reliability of information exist as socially valuable or desirable?

**Legal –** How should intellectual property models be adjusted regarding transformations of informal content into digital or digitised goods?

The co-creation of this prototype was coordinated by the EU Policy Lab of the Joint Research Centre, with the contributions of Enrique Encinas (M-ITI / Madeira Interactive Technologies Institute), James Auger (M-ITI / Madeira Interactive Technologies Institute), Jaya Klara Brekke (Durham University), Juan Blanco (Consesys Systems) and Carlotta de Ninni (Mycelia).

programmatically and conditionally, with automatic asset releases when fulfilling services in a sequential manner, or incurring penalties if not fulfilled. There is an opportunity for organisations to leverage smart contract technology by integrating smart contract code and blockchain for the purpose of overseeing agreements and licensing (Morabito, 2017).

However, **smart contract technology has yet to reach a mature stage where it can process a large number of transactions and update and revise contracts across a multiparty network** (Howard, 2018). Other challenges are related to current regulatory constraints and a need for wider recognition of blockchain within the IP community (Sellin, 2017). Possible regulatory constraints include questions regarding the **issues of applicable laws and jurisdiction, the enforceability of smart IP rights (IP rights recorded in distributed ledgers), reliable rules and definitions for smart contracts, data security and privacy concerns** (Bodó, Gervais and Quintais, 2018). Yet various governmental agencies and IP registers, for example the European Union Intellectual Property Office (Clark, 2018), are looking into the technology's capabilities.

Another blockchain application in this sector could be the **curation and management of metadata regarding any type of digital work.** A distributed and verified database could host valuable information which is currently mainly opaque except for distributors, publishers and/or record labels, including how many times a song or a book was played, watched or read online, where or by which means it was bought, and even by whom. Additional information of potential interest for both creators and consumers could be stored, such as the instruments used in the production of a song, where it was composed, the musicians involved, direct comments and/or feedback, and so on (Bello Perez, 2016). The general expectation around the use of blockchain is that it could **support alternative business models for digital works according to the conditions set by their rights owners (either for free under certain conditions, or at a price), and ultimately change the dynamics between creators, authors, users and distributors.** This would imply defining and experimenting with new incentives to connect such a different set of stakeholders through greater transparency and data sharing.

It can be argued that open and trusted access to data could create knowledge feedback loops between diverse stakeholders and foster ground-breaking data-driven applications running not only on blockchain, but deploying AI, machine learning, data analytics and so on (Dubber, 2017). Yet, concerns remain, for instance, about excessive commoditisation of digital works in a future where all content is catalogued, tracked and monetised.

In the long run, multi-stakeholder inclusive innovation ecosystems could be running on a blockchain with no central authority, with multiple providers depending on the function needed, and with full interoperability between different services (Ericson et al., 2016). This would be a modular approach for an open and transparent meta-system running with individual systems, not only adapted to the specific problems they are designed to solve but also fully interoperable with each other. This would be accomplished by using open standards and accessible data running on blockchain systems, and in compliance with independent certification and/or regulatory frameworks within a multi-stakeholder model.

## 5.5. Health and biopharmaceuticals

In the health sector, patients, doctors, hospitals and other healthcare providers could store **electronic health records in blockchain-based decentralised management systems** in which they can **encrypt personal and/or sensitive information and grant access to records only to authorised parties via appropriate credentials** (Ekblaw et al., 2016; Deloitte, 2016a).

**The capacity to record and authenticate medical data and customise its use for other parties could leverage the informational and economic value of such data.** It could stimulate **new business models for privacy-preserving solutions, personalised medicine, data sharing for drug, treatment and public health research purposes, or even selling, buying and re-marketing** for any number of stakeholders.

For instance, blockchain could have an impact on accountability and transparency in clinical trials reporting and management processes (Benchoufi and Ravaud, 2017). Data and metadata that needs to be circulated in a clinical trial between multiple stakeholders (sponsors, researchers, patient groups, regulatory agencies, registries, statisticians, drug suppliers, patients, data manager, trial monitors, etc.) could be time-stamped and cryptographically stored in a blockchain. Researchers could benefit significantly from sharing anonymised raw data, datasets or statistical analysis plans in clinical trials through distributed and secure channels. Smart contracts could also be used for clinical-trial phase control. Patients could give specific consent for data analysis, for example, on the condition that the database is not shared with third parties and/or used for commercial purposes.

**Data confidentiality and security are major concerns** in this sector, so any blockchain solutions need to put in place **strong privacy mechanisms in compliance with data protection regulation.** For example, from the patient's viewpoint, her or his data could be pseudonymised or anonymised through robust de-identification and cryptographic mechanisms. Patients could implement dynamic consents through smart contracts – that is, by defining data access rights stating, for instance, the type of data to be given, intended uses, authorised third parties, conditions for revocation or storage limits. Under these conditions, they could more easily share their records and ask different doctors for second opinions, find other patients with a similar condition, or give their information to biomedical centres and universities for research purposes (Panetta and Cristofaro, 2016).

Overall, blockchain could introduce changes on how data is used and managed within the health sector. Nowadays, health data is fragmented, siloed and opaque, or under the control of a few dominant stakeholders. Blockchain could provide permanent records to be verified and accessed much quicker and with greater security and openness for everyone involved, or with the adequate authorisation.

For other applications interlinked with different sectors, such as transport and logistics, blockchain systems could be used to record

“Data confidentiality and security are major concerns, *so any solutions need to put in place strong privacy mechanisms in compliance with data protection regulation.*”

and track biopharmaceutical products along their supply chains (Modum.io, 2017). Drugs and other products could be tagged with IoT devices, authenticated and recorded in a blockchain. This could prevent and/or enable quicker detection of counterfeits, theft or misplacements along a complex multi-party network of producers, manufacturers, regulatory agencies, suppliers, distributors and others. It could help to keep track of the environmental conditions required for the transport of pharmaceuticals and other healthcare products, such as temperature and time. Overall, blockchain-based systems could support companies to prove

## BOX 9. Care AI[53]

What if you could anonymise your personal health data and share it in exchange for professional healthcare? Care AI is a service providing access to basic healthcare in exchange for anonymised personal health data. Its operation makes medical information available for public and private third-party entities in data market places which run automatically through smart contracts.

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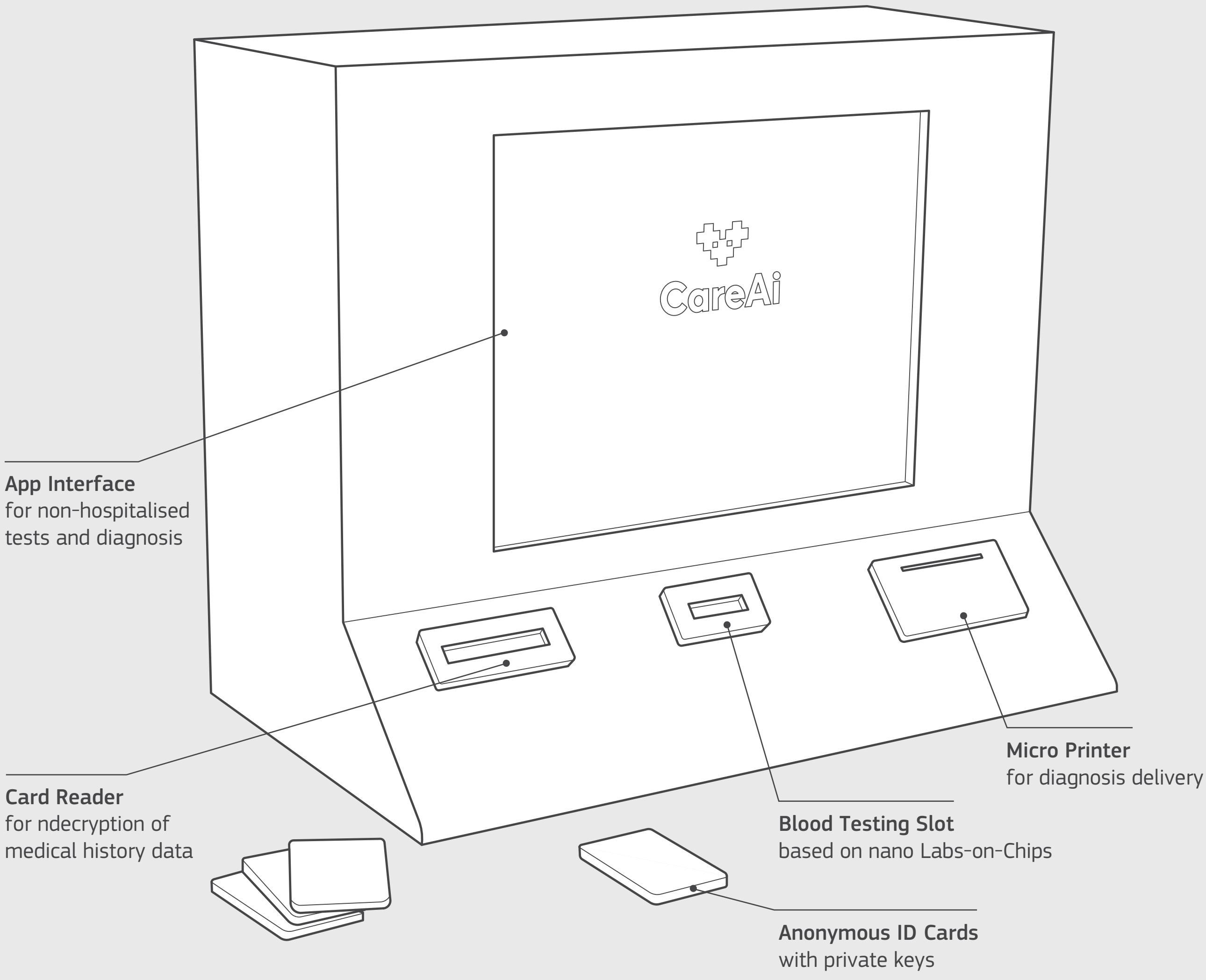
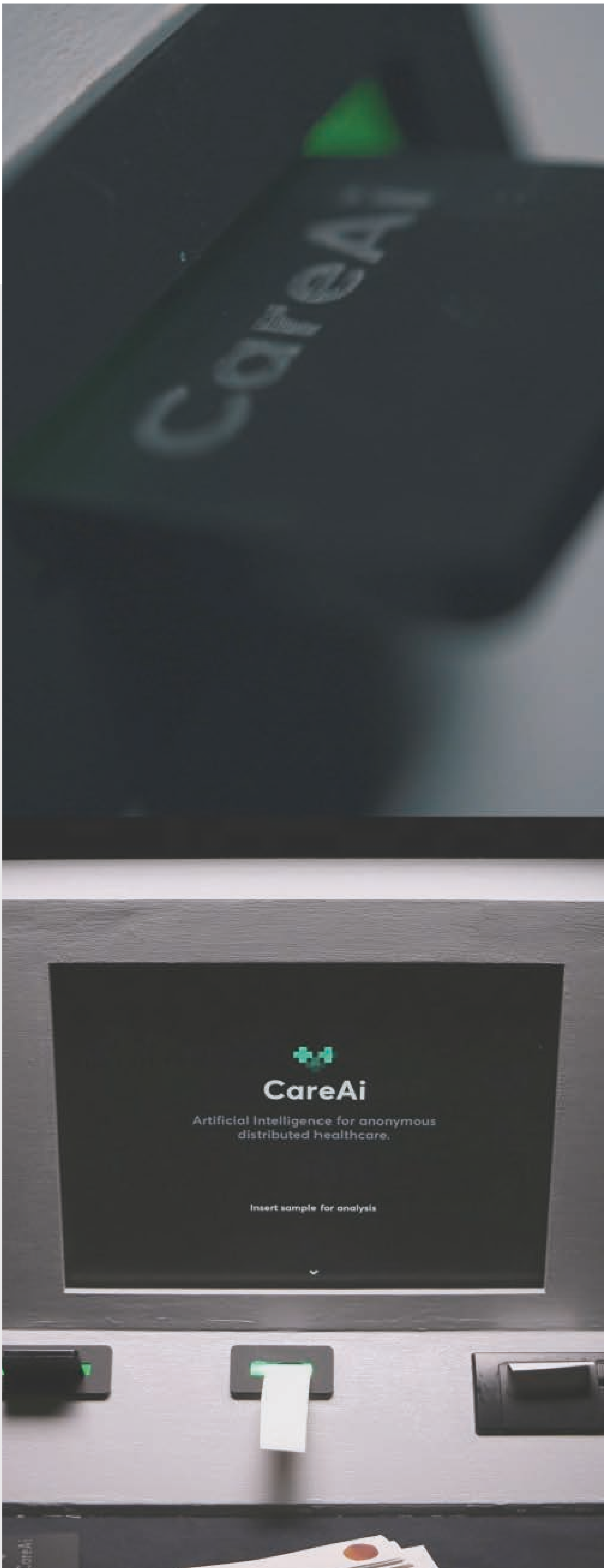
#Health #IdentityManagement #Authentication #Anonymisation #ArtificialIntelligence #SmartContracts #InvisiblePopulations



compliance with mandatory quality controls, speed up logistics, minimise errors and costs, and improve the transparency of the whole supply chain.




**Automated Networks** of CareAI Points provide non-hospitalised test and diagnosis for people without access to traditional healthcare. Labs-on-Chips are distributed for free and include materials for blood sampling and testing.

**Anonymous ID Cards** allow users to donate personal health data in exchange for healthcare. A private key decrypts the card holder's medical history and new collected data is uploaded into a smart contract.

**Public or Private** entities can pay to access info for research, planning, or other purposes. This subsidises medical treatments while also paying procedures, owners and maintainers of Care AI Points.

**P** E S T **L** E

**Policy –** How would automated health service points impact integrated healthcare solutions which target populations at risk?

**Legal –** How could regulatory frameworks prevent cases of misuse and exploitation of data when exchanged for basic services?

The co-creation of this prototype was coordinated by the EU Policy Lab of the Joint Research Centre, with the contributions of Gui Seiz (FabLab Barcelona, IAAC / Institute for Advanced Architecture of Catalonia), Jordi Planas (Vimod Studio), Maciej Hirsz (Parity), Ivo Lõhmus (Guardtime), Annalisa Pelizza (University of Twente) and Lucas Peña (Ideas for Change).



## SUMMARY

Interest in blockchain's potential in the public sector can be seen in an increase in experimentation. Benefits relate to better security (enhancement of data integrity, tamper-resistance and consistency between organisations), efficiency gains (reduced processing time, lower costs) and a greater level of trust in public record-keeping. So far, blockchain has offered a set of incremental rather than radical innovations, as sometimes portrayed, although some of them can make a huge economic difference. However, the number of projects is limited. How massive these impacts will be has yet to be seen, as the technology is in its infancy and must overcome several bottlenecks related to scalability, performance and confidentiality. There are also blockchain deployments where it does not offer clear value added when compared to centralised systems, or it does not introduce a new service or paradigmatic change to citizen-government relations.

# TRANSFORMING GOVERNMENT AND THE PUBLIC SECTOR

## 6.1. Land and property transactions

Blockchain is a new general-purpose information technology for record-keeping and the settlement of complex transactions (Davidson et al., 2016). These features have specific implications in the context of public administrations and governments, for instance.

In public administrations, numerous registries containing citizen, tax or land title records are costly in terms of maintenance, prone to human errors, and exposed to one point of failure. Public administrations can use this technology for the distributed registration of documents and assets rather than solely registering in a centralised way. **The benefits of blockchain technology for public services are argued to include the ability to provide tailored services for specific citizens, greater trust in governments and improved automation, transparency and auditability** (Atzori, 2015, 2017; Norta, 2015; Swan, 2015; Van Zuidam, 2017).

**Distributed registration and exchange of citizen records,** such as birth certificates, land titles or criminal records, could be particularly useful for citizens in countries where the centralised information infrastructure is either less developed, unreliable or corrupted.

As one of eight ongoing projects on blockchain for digital government in Europe recently analysed by the JRC (Allessie et al., 2019), the **National Agency of Public Registry (NAPR) of the Republic of Georgia, in partnership with The Bitfury Group,** is using blockchain technology to provide its citizens with a digital certificate of their land titles. This blockchain pilot currently enables registration of the purchases and sales of land titles and registration of new land titles (over 100 000 since April 2016). The aim is to increase public confidence in property-related record-keeping and ultimately to help Georgia fight corruption and disputes over property claims (Eurasianet, 2017; The Bitfury Group, 2017). In the future, the system is also expected to provide registration of the demolition of property, mortgages and rentals, and notary services (Forbes, 2017a).

> Blockchain has offered a set of incremental rather than radical innovations, although some of them can make a huge economic difference.

In this specific pilot, the blockchain system is private in terms of who can validate the transactions, which means that the actual transaction validation is done by a group of known servers or nodes. However, data is then hashed and the transaction is validated by the public Bitcoin blockchain, which creates transparency on the existence of the land title for all citizens. Therefore, it is a mix of public permissioned and private blockchain.

The process of adding or changing a land title through this system is displayed below *(Figure 17)*, in the following steps:

1. A citizen can initiate a request to the service hall or notary for the registration or verification of a land title extract;
2. The notary registers the land titles on the private Exonum blockchain;
3. The private Exonum blockchain hashes are anchored in the public Bitcoin blockchain which guarantees the integrity of all transactions;
4. NAPR provides the citizen with a digital certificate of their asset, supported with cryptographical proof of the extract's originality, published in the Bitcoin blockchain;
5. A citizen can now verify if a land title is legitimate.

Drawing on JRC's case study analysis (Allessie et al., 2019), this blockchain deployment offers a mix of **quantitative and qualitative benefits:**

- **Significant reduction in the land-title registration and verification time:** whereas in the past these actions took around one to three days to process, the transaction time with blockchain has been cut to a matter of minutes;
- Increased transparency in the registration process of land titles;

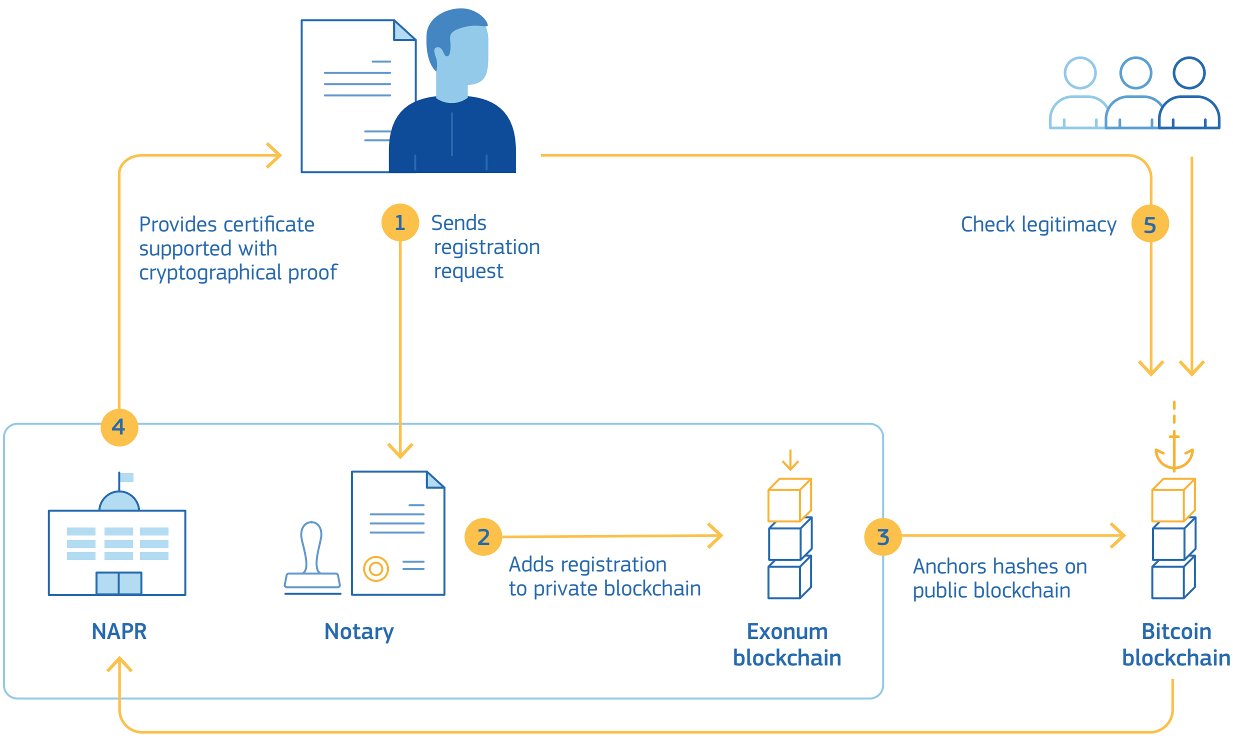



**Figure 17:** Land title registration process used by NAPR in Georgia
**Source:** Allessie et al., 2019

- More reliability for citizens concerning the accuracy of the data stored at NAPR;
- **Efficiency gains** are achieved in the system as the time to verify a certificate has been reduced from a matter of days to a matter of seconds;
- **Operational costs have been cut by** up to 90 % for the land-title registering service.

The costs involved in implementation of the new system are mainly non-recurring, related to customisation of the Exonum protocol and integration with NAPR and the notaries. Citizens are not charged any extra fees. It is noteworthy that several cost items in the old system remain (such as maintenance of a central digital record system) as the blockchain system is not a substitute for a legacy solution. Furthermore, checking a request initiated by a citizen is still done manually by the notary.

**In terms of key takeaways, the main drivers for NAPR blockchain pilot are the greater security and reliability of the digital certificates.** Verification of certificates is made in the public blockchain, which is beyond the control of any participant or group of participants. This independent and incorruptible layer helps to combat fraud and prevent land-title disputes. **However, the blockchain system neither provides full disintermediation of organisations nor replaces existing systems.** It merely provides more new functionality in the form of additional assurance to citizens. For this reason, its integration within legacy systems has been relatively easy.

The ease of implementation and the success of this blockchain-based system are largely the result of the success and autonomy of the NAPR organisation in the Republic of Georgia. The organisation has little bureaucracy and supports bottom-up innovation. Other key success factors relate, for instance, to the legal provision of making land-title data public (in other countries it is considered private), and automation of the registration process and easy-to-use web interface for citizens.

Another application of blockchain systems in public administration concerns property or real estate transaction procedures. Their security and transparency are important because of the high value at stake. Yet the settlement process is slow and costly due to its exposure to various risks and an overall lack of trust in the registration systems currently in place.

In September 2016, **the Swedish Mapping, Cadastral and Land Registration Authority, together with Landshypotek Bank, SBAB, Telia, ChromaWay and Kairos Future** (ChromaWay, 2017a), set up a blockchain-based pilot to redefine real estate transactions and mortgage deeds. This project attempts to tackle both the distrust between parties in real estate transfers and to speed up transactions.

The solution introduces a completely new blockchain-based workflow that streamlines and secures the process of transferring a property title. The citizen logs on to the ChromaWay web

> “The blockchain system neither provides *full disintermediation of organisations nor replaces existing systems.*”

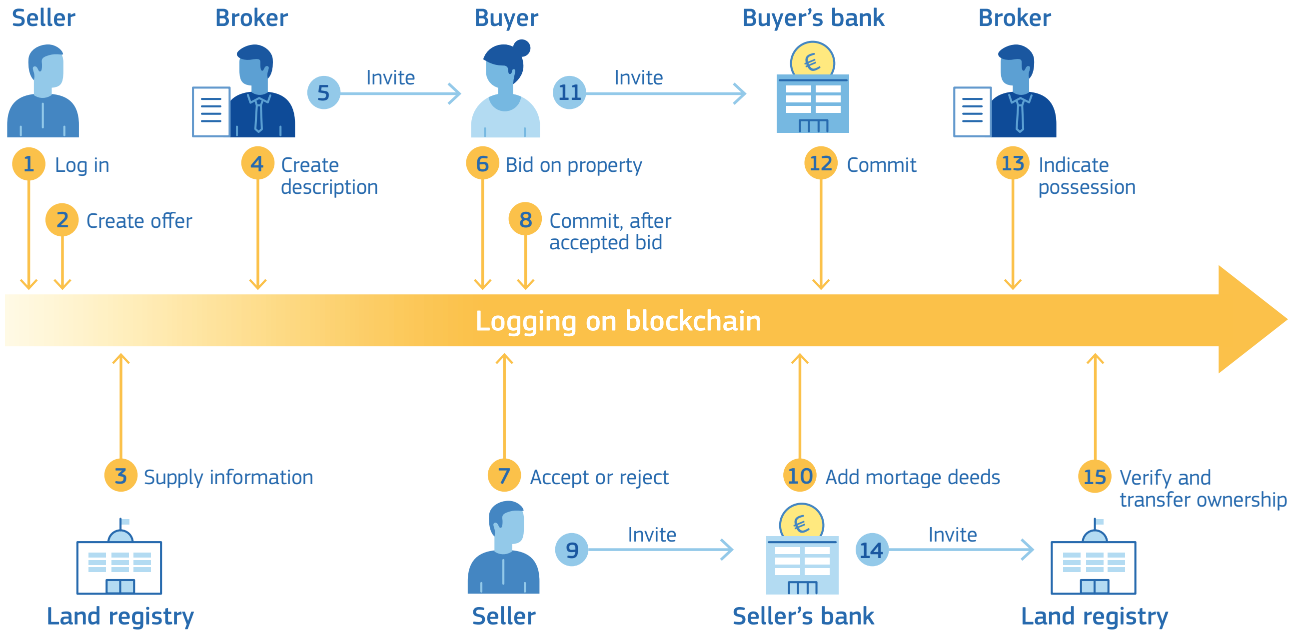



**Figure 18:** Real estate transfer workflow in the ChromaWay pilot
**Source:** Allessie et al., 2019

browser, which allows access to Esplix, a smart contract workflow mechanism. The system interfaces with the Swedish Land Registry which is responsible for storing land titles. The blockchain only stores the state of the system after the execution of each step in the workflow. The entire transaction process underlying a property transfer (involving buyer, seller, real estate agent, banks and land registry) is described below and depicted in *Figure 18*.

This blockchain pilot is defined as a private permissioned blockchain which stores anonymously transaction data submitted by different actors. A centralised ID system is currently used to define who can transact and see the data, and the transactions are validated by known nodes. Although the project has been active for two years, this pilot is still in its PoC phase – i.e. it has not been integrated into the real estate agents' environment yet. Furthermore, retrieving from blockchain is not yet automatic with some technical hurdles still to be overcome.

**Reduced transaction costs** stand out as one of the main benefits of this pilot. Property transaction time drops from a number of weeks to a matter of minutes or hours. Currently, the cost of insurance safeguarding a real estate can reach up to 10 % of the purchasing value. In the ChromaWay system, this could be reduced to 1 %. Other positive effects, such as **reduced paperwork and fraud,** also translate into financial gains. Another key benefit comes from an **optimised workflow** which enables greater trust in these high-value transactions, and potentially improved market operation and an increased liquidity of assets. **Improved resilience** to any modifications to the storage system by external actors, given the distributed nature of the blockchain platform, is also emphasised.

The costs involved in the project include integration and operation. As to the first, to implement a system suited to all the stakeholders requires a lot of effort for its integration into legacy systems and making it interoperable with banking systems. With reference to operational costs, this is expected to be higher compared to a centralised database solution (ChromaWay, 2017b). The cost is increased by the continuous replication of the consortium database which is part of the blockchain protocol.

Overall, this type of pilot demonstrates **the potential of blockchain-based automation in achieving huge efficiency gains in settling multi-party transactions and reducing uncertainty among agents.** For example, in the ChromaWay pilot, the smart contract workflow at least partially disintermediates traditional notaries. In the current system, the notary verifies the transacting parties' identities and checks the authenticity of documents and signatures. She or he also verifies that the statements expressed by the parties are consistent with real-world facts and free will. In the new system, these elements will be provided automatically in electronic format.

However, this pilot also highlights **a number of hurdles that inhibit the use of blockchain technology for complex and high-value transactions** such as real estate transfers. For instance, the service still **relies on inputs from centralised systems** for the provision of property details and the electronic authentication of users. In particular, the **electronic identity system must be recognised by the government** and linked to specific natural or legal persons. There are also further **doubts about how the external consistency of electronically submitted statements** can be assured, without and outside an arbiter.

## 6.2. Identity management

Accessing online services or performing online transactions rely on citizens disclosing relevant information or providing proof of identity. Citizens are usually required to give financial and personal details which are stored on centralised or government-controlled platforms or in databases. Many such databases are exposed to serious security issues, as attested by news of extensive breaches that expose users' personal information.

In this respect, who processes, stores and owns such data, how and for what purposes are at the core of recent and ongoing European regulatory initiatives within the Digital Single Market strategy. This includes the draft Regulation on a framework for the free flow of non-personal data in the EU (EC, 2017), the EU General Data Protection Regulation (GDPR) (Regulation (EU) 2016/679), and the Regulation on electronic identification and trust services for electronic transactions in the internal market (eIDAS) (Regulation (EU) No 910/2014), among others (e.g. EC, 2017f).

**Blockchain technology could support new types of solutions for identity and access management** by introducing decentralised models of ownership, management, representation and attestation of a person's identity. As a use case[54], **the Swiss municipality of Zug has launched a government-issued identity on Ethereum called uPort.** The aim is to use this identity for trusted

> "Blockchain technology could introduce decentralised models of *ownership, management, representation and attestation of a person's identity.*"

and self-reliant e-government services, enabling citizens to selectively disclose specific information to specific companies and public services.

Currently, only proof of residency is provided in this early-stage pilot, which started on 15 November 2017 with a digital, blockchain-based identity certified by the City of Zug Resident Control. To date, around 300 of Zug's 30 000 citizens have registered. The project aims, however, to expand to other public services run by the local authorities, like surveys, e-voting, bike renting, book borrowing, tax declarations and parking payments.

The consortium governing the uPort application has a public-private hybrid structure, including ConsenSys, TI&M, and the Institute for Financial Services Zug (IFZ) at the Lucerne University of Economics and the municipality of Zug. Development of the services and technology is dependent on the other public organisations, business and the open source community of uPort and Ethereum.

The uPort app creates a unique and unchangeable crypto address in the blockchain and links it to the local user wallet, located on a smartphone. The process of registering for uPort identity is depicted in *Figure 19*, as follows:

1. Citizens of Zug first download the uPort app on a mobile phone;

2. An uPort identity is automatically created, which is a public address of a smart contract on the Ethereum blockchain;

3. Citizens register their uPort ID on the website of the municipality of Zug, adding their current Zug ID number and date of birth as additional personal information;

4. Citizens use the app to cryptographically sign the registration request which is then sent to the municipality offices;

5. Citizens go to the municipality offices to verify the request in person;

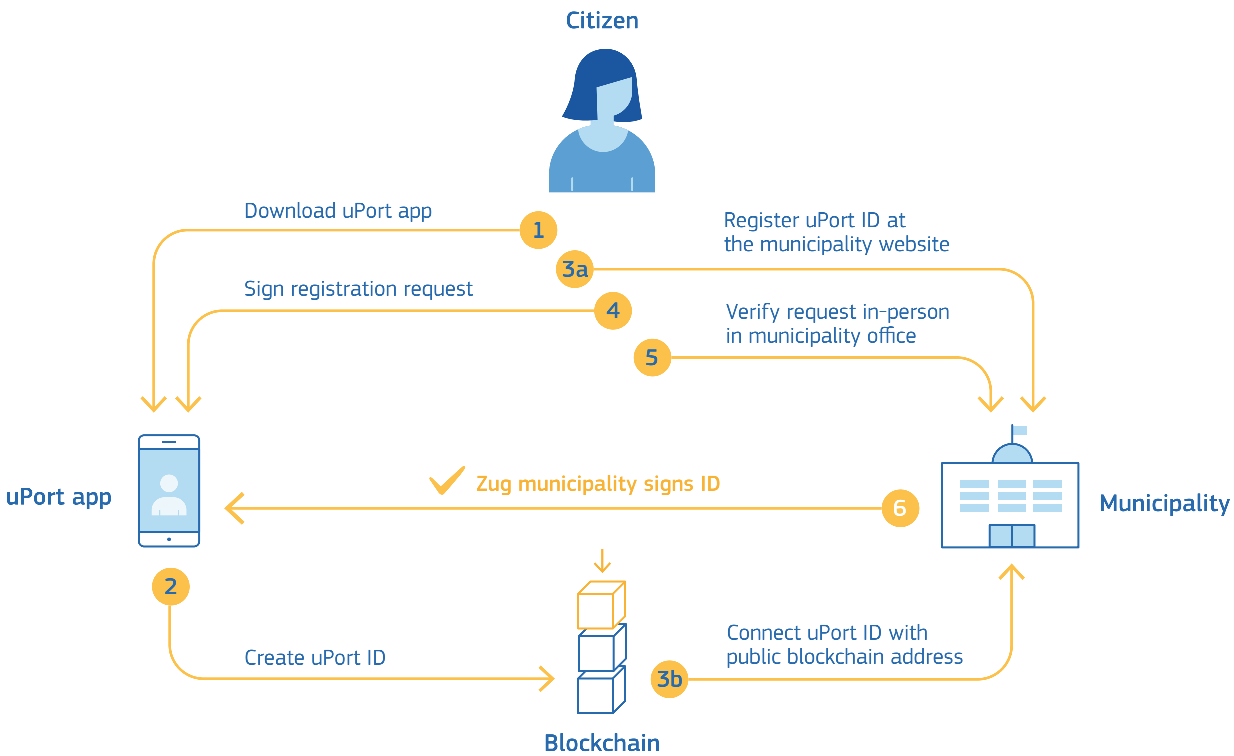



**Figure 19:** Overview of uPort process
**Source:** Allessie et al., 2019

6. The Zug municipality cryptographically signs the ID and automatically sends verification to the uPort app. Finally, the uPort identity is recognised as an official government-issued identity. This coupling process has to be done only once.

The JRC has identified a **series of benefits** in this blockchain pilot (Allessie et al., 2019).

First, **operational cost savings** are expected as the Zug municipality is moving away from storing personal data to simply checking a person's identity for the services it provides.

Secondly, this type of blockchain system can **reduce the risk of cyberattacks and infrastructure costs.** A self-sovereign identity solution can reduce the need for companies and other organisations to maintain centralised repositories of identification information. Oncethe ownership and attestation of identities has been shifted to citizens, there is less or no need to host servers with central databases.

Finally, new forms of attestation generate **time savings for citizens in terms of accessing services.** If many services, businesses and public administration incorporate the uPort identity for accessing their services, which could save time in setting up and managing specific identities for each of those services. Efficiency gains could also be achieved as services would no longer require a password and could be integrated with each other since the authentication mechanisms would match.

The costs of this particular pilot are associated with both **development and operation.** As regards the first, whilst the cost of project development and management remain undisclosed, about 10 full-time equivalents have been spent on system integration over the past 8 months. As for the second, in the future, only a municipality clerk is required to operate the system. However, transactions cost could become an important factor, as adding each new user is estimated to cost USD 105 if the pilot is moved to the main Ethereum net. With 300 000 citizens in Zug each requiring a transaction for registration, the cost could amount to USD 3 000 000. Since statements sent by smart contracts on the main Ethereum are also costly, using uPort identity may involve additional costs.

In terms of key takeaways, users of uPort can selectively release information to parties for authentication, thereby gaining greater control over their identity. They can choose how much data, to whom and when to disclose it. As a consequence, in effect, companies and apps only receive a minimal set of personal data from the user, as postulated by the GDPR. Also personal data is stored in a secure, encrypted form on a mobile device. Attestations are always sent off-chain and can be used for authentication by any service provider or public institution, thus generating efficiency and security gains for both sides.

The uPort decentralised identity project in Zug stands out as an example of **potential blockchain applications which allow citizens to create self-sovereign identity that is attested by the government.** The project design utilises **smart contracts for management and the controllable sharing of personal data,** providing a prime example of how blockchain can be used to empower citizens. **Yet, as in this case, a decentralised identity system still requires a centralised, government-owned system which exists in parallel.**

## 6.3. Allocation of public benefits

**Blockchain systems can allow for more efficiency, transparency and programmability of public funding, specifically by adding the functionalities of distributed registration, membership management, information exchange and automatic execution through smart contracts.** Operating as decentralised networks, blockchain systems can enable all participating users (from public administrations and private operators to citizens) to manage their transactions without necessarily relying on additional third parties or intermediaries. Extra security and accountability provided by blockchain systems as tamper-resistant records can bring considerable benefits to a number of government services, ranging from public aid to social transfers.

Taking as an example the increasing complexity of professional careers, where employees have multiple employers and job types over their lifespan, this impacts pension administration as future pensioners often sign up to multiple personal pension schemes with various pension-fund providers. In 2018, **APG and PGGM, two of the largest pension providers in the Netherlands, started the Pension Infrastructure pilot as a complete community-based pension administration blockchain back-office.** The aim is to realise a more flexible and transparent pension administration system for citizens, while achieving significantly lower costs.

This pilot includes a number of stakeholders, including employers, the national identity service, the tax authority, payroll providers, pension funds, service providers and citizens. An overview is provided in *Figure 20*. The system provides different functionalities based on the role of the actor. For the tax authority, for example, it gives an integral image of the contributions collected by a specific individual across many pension funds. For a citizen, it provides real-time insights into their pension scheme and pension balance. Employers can directly execute and log a salary change. Regulators do not have an active role although they can see some of the data.

At the moment, the project is a PoC rather than a pilot, as the functionalities provided are incomplete. The test case is based on the pension

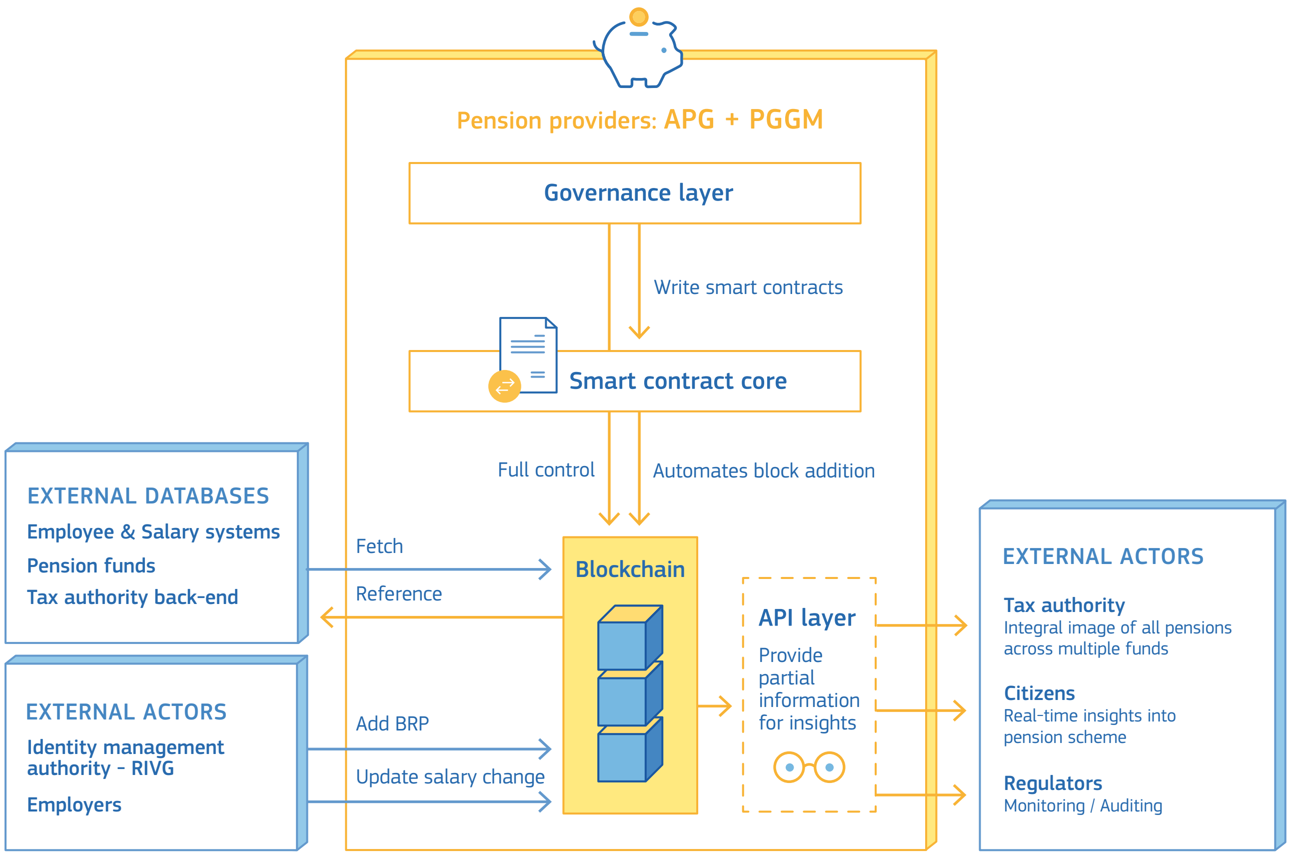



**Figure 20:** Overview of Pension Infrastructure project
**Source:** Allessie et al., 2019

fund for APG's own personnel and around 5 000 users are currently participating. A tweaked version of the Ethereum protocol is used which creates private blockchain architecture. The nodes in the network are known nodes representing the stakeholders involved in the infrastructure. Thus, the blockchain archetype used is private permissioned.

The benefits of this blockchain-based pilot include (Allessie et al., 2019) **cost savings on pension administration** that traditionally entail a great deal of administration, checks, human labour and copying in a complex environment with governmental and private-sector systems. This results in high costs and poses a risk for data corruption in existing databases. It is estimated that blockchain could save EUR 500 million of the overall cost of EUR 1 billion.

In addition, this pilot can also bring **efficiencies related to the creation of a distributed database, which is a single source of truth for all the different parties.** Furthermore, from the citizen's perspective, transaction costs are lowered as the information, although distributed, is accessible via one single interface, based on the personal pension smart contracts. The average participation cost for citizens in pension funds are currently estimated at EUR 80 per year, the aim being to lower that to EUR 15 per year.

> "Shared database and workflow automation blockchain functionalities *are leveraged to generate significant efficiencies in the pension system.*"

To summarise, the PI pilot in the Netherlands focuses on all aspects of the ecosystem, from citizens managing their own pension schemes to automatic tax declarations to the authorities. **Shared database and workflow automation blockchain functionalities are leveraged to generate significant efficiencies in the administration and regulation of the pension system. However, the scale and complexity of the system go beyond current technological developments.** In particular, the large volume of transactions to be processed with smart contracts constitutes a major challenge. Even though all actors are represented, the complexity of this infrastructure means that this project is still in the very early stage of its life cycle.

Another application of blockchain systems in public spending concerns, for instance, the **targeting and management of redistribution programmes.** Since 2016, the **Dutch municipality of Groningen has used a blockchain infrastructure to provide discounted services to people with low incomes in order to promote inclusivity in the city.** Detailed spending conditions can be programmed in the smart contract, such as profiles of eligible beneficiaries, thresholds, limits and authorised providers. These smart vouchers can then be used in sports clubs, access to swimming pools or the cinema, or to subsidise solar panels for homeowners.

The system works as follows *(Figure 21):*

1. A citizen applies for the 'Stadjerspas' at the municipality, giving her or his name, address and citizen number;

2. The municipality checks whether the registered citizen is eligible for any smart vouchers. If so, the municipality sets up an anonymised user identity on the blockchain linked to personal details stored off-chain;

3. The municipality grants the citizen a Stadjerspas accompanied by a personal QR code referencing ID for the blockchain-based smart voucher system;

4. The citizen uses the services of the participating businesses that scan the QR code on the pass to activate the smart voucher to calculate a discount;

5. After a certain period, SEPA payments are made from the municipality to the businesses.

Over 20 000 citizens and service providers are registered in the programme and around 4 000 smart voucher transactions occur each month.

Initially, when the system was created in 2015, the Bitcoin blockchain protocol was used. However, the system has now transferred to Zcash as the transaction costs are significantly lower. The system has its own smart contract logic on top of this blockchain protocol. Every transaction is stored, excluding the details of the actual transaction. Validation is performed on a public blockchain, although the users who can transact are permissioned, making the system a public permissioned blockchain.

This blockchain deployment is expected to bring a number of positive effects, including **improvements in the efficiency of allocating public funds.** This effect is mainly realised from a public accountability and redistribution policy perspective, as the programmable smart vouchers assure that every euro dedicated to a specific purpose and beneficiary is spent accordingly. Blockchain minimises the room for economic arbitrage in the form of a transfer of subsidised service. It can also bring **operational efficiency**

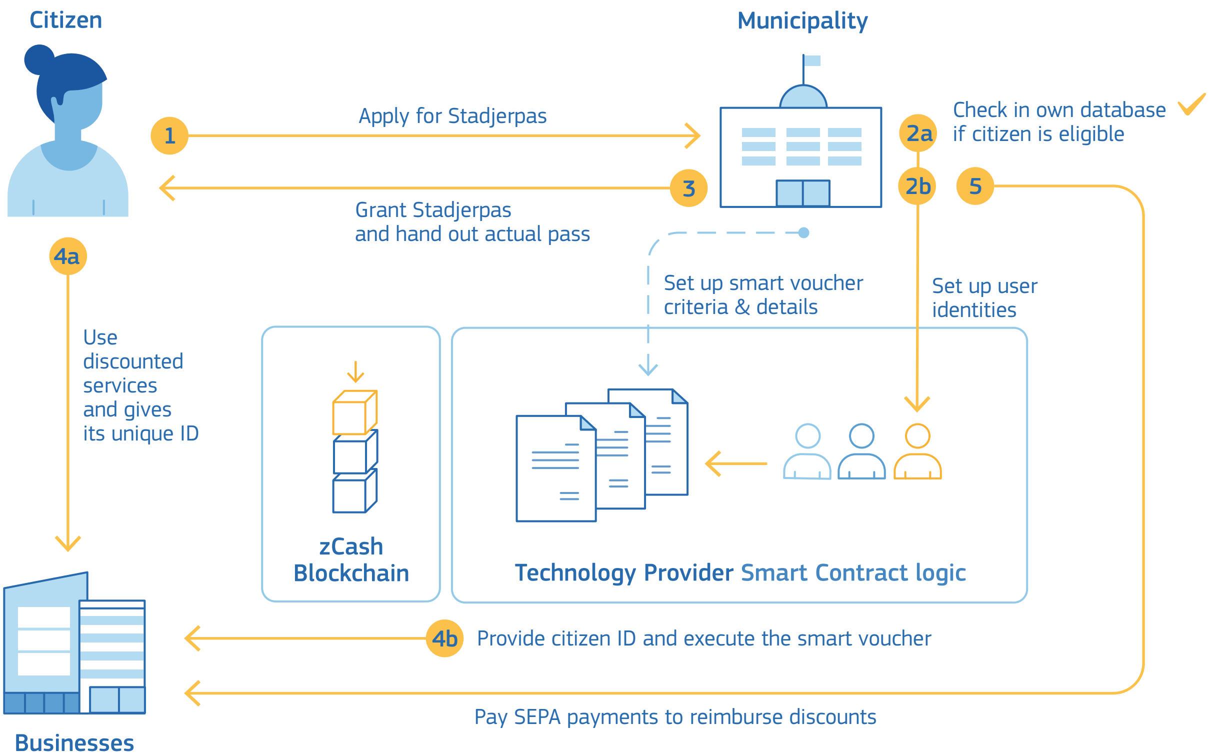



**Figure 21:** Stadjerspas smart vouchers process flow
**Source:** Allessie et al., 2019

**gains** for the municipality. As a blockchain creates an audible ledger for verification and audit purposes, it **can facilitate automatic payments.** It is expected that the **need for paper and human labour procedures at the municipality will be reduced.**

These and similar pilots highlight **the potential of blockchain systems for managing, targeting and allocating social benefits, grants, subsidies or aid.** For instance, in the Stadjerspas smart voucher pilot, blockchain deployment ensures that public money reserved for a specified purpose is dedicated to that purpose alone and directed towards a desired group of beneficiaries.
The benefits of a smart contract-based solution include greater **public accountability and auditability of public spending** in this domain, as they are pre-specified to be spent at specific places and cannot be copied.

In addition, the use of blockchain can **increase security, resilience and transparency of information in such applications.** It eliminates a single point of failure thereby reducing the risk of an external attack. Information integrity is increased since, in the case of an attack or the failure of a node, data is still stored in other nodes. It also improves data reliability, as the copying and replication of data across the various participants is reduced and only needs to be entered once. Furthermore, there is greater transparency for all users involved as every transaction is recorded and cannot be changed by one actor. This allows regulators to carry out overviews of the entire system without information asymmetry.

> "The benefits of a smart contract-based solution include *greater public accountability and auditability of public spending.*"

## 6.4. Certificates and accreditation

Looking at **blockchain applications for certification in education,** this technology could help higher education institutions to notarise digital certificates. This could be done with **more scale and speed, transparency and visibility and, above all, with immediate trust in the credentials that attest the capabilities of the graduate or jobseeker** applying for a job. Ultimately, it could have an impact on the employment prospects and professional careers of students and graduates.

In education, certificates are used to attest that a person has taken part in an education programme and/or has achieved specific learning outcomes, which are often checked via assessment practices. Certificates can be formal (e.g. leading to a professional qualification) or non-formal (e.g. certificates of attendance or participation in learning activities); they can also take various formats, such as paper-based or digital. Accreditation in education is a procedure by which an authoritative body (e.g. a ministry or accreditation agency) gives an organisation or person the right to issue a trusted and valid certificate or credential which meets preset standards and quality assurance measures.

The forms in which education certificates are issued to learners have been evolving. Paper-based certificates present some limitations that a digitally based and blockchain-registered certificate could overcome. These include, among others, the risk of forgery, replacement costs, and slow verification. The digital but non-blockchain-registered certificate can be verified and revoked more easily, but if it does not have a digital signature it could also be forged. And even if it does have a digital signature, if this signature is not based on an open standard which can be universally verified the certificate's verification procedure can be locked by specific software ecosystems, thereby reducing its suitability in various contexts.

In turn, **a blockchain-registered certificate, for example in the form of a digital certificate or open badge, can be verified by anyone who has access to the blockchain.** Or this could be done via an automatic open-source verification system such as the **Blockcerts Universal Verifier.** Looking into Blockcerts in more detail, this **open standard for academic records has been used, for example, in the pilot launched by the Maltese government** in October 2017.

> "A blockchain-registered certificate, in the form of a digital certificate or open badge, *can be verified by anyone who has access to the blockchain.*"

Using blockchain as the infrastructure, Blockcerts focuses on every aspect of the value chain: creation, issuing, viewing and verification of certificates (Inamorato dos Santos, 2017). The process comprises the following steps *(Figure 22)*:

1. The university sends a request to the citizen to download the Blockcerts app/wallet;
2. The citizen installs the wallet and accepts the university as the issuer, while generating a private and public key;
3. The Blockcerts app sends the citizen's public key to the university;
4. The university creates a digital certificate, including the citizen's public key, in the Blockcerts issuer interface application. This certificate is signed with the university's private key;
5. The university hashes the certificate in the Blockcerts issuer environment and saves the hash in the Bitcoin blockchain;
6. The university emails the certificate and the hash stored on the blockchain to the citizen;
7. The citizen can provide third parties with the certificate and the URL;
8. Third parties enter the certificate and the URL in the Blockcerts online verifier, which checks if the certificate hash matches the hash recorded on the Bitcoin blockchain. If the hash is found, the certificate is validated. The third party now has proof of the document's originality.

To summarise, no intermediary parties are required to validate a blockchain-based certificate.

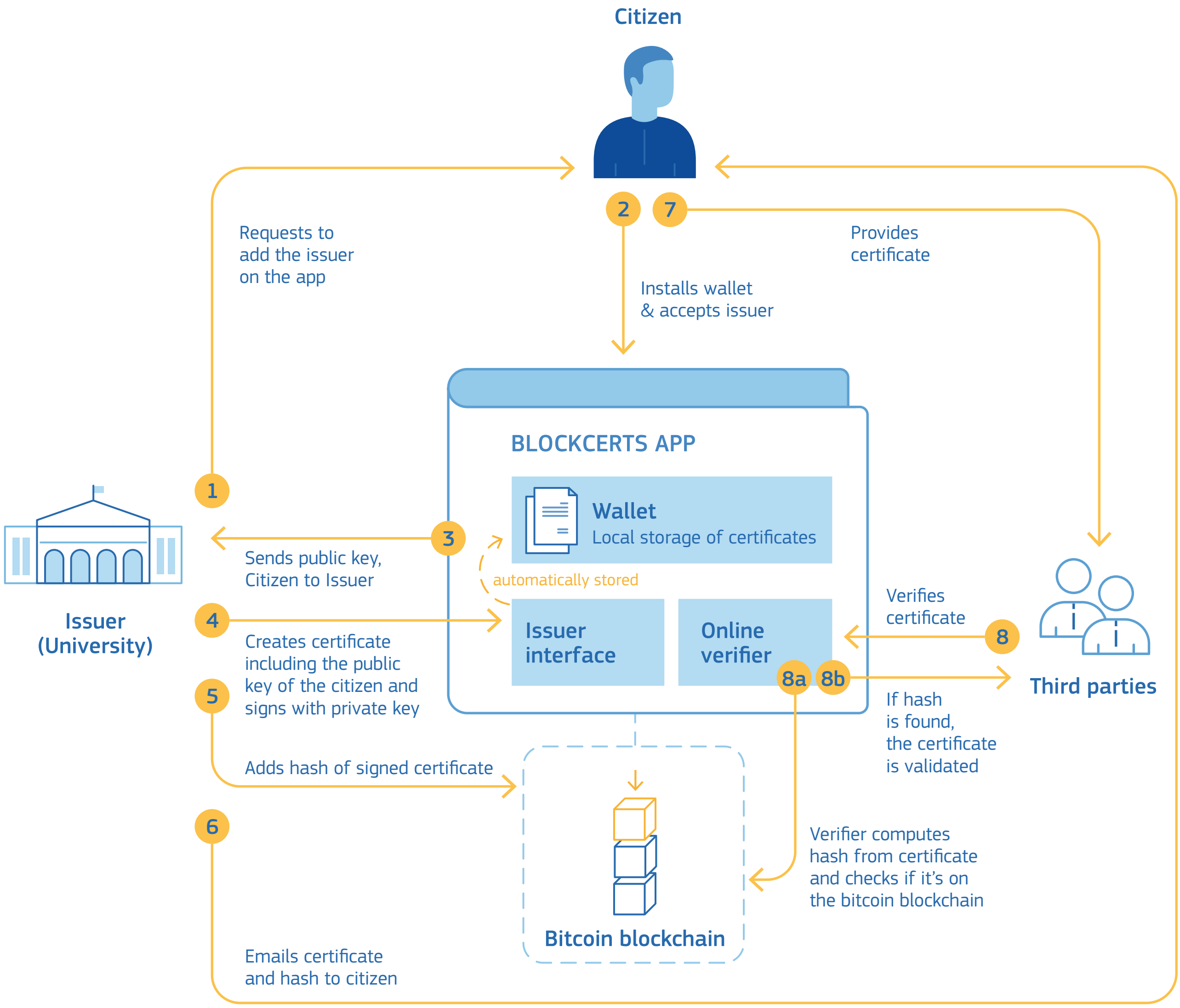



**Figure 22:** Blockcerts certificate verification process
**Source:** Allessie et al., 2019

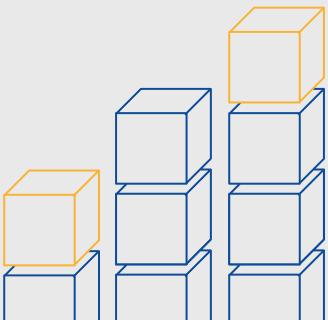
Even if the accredited issuing organisation disappears over time, this certificate still can be verified. In cases where greater control over data is placed on the learner, only a certificate's hash is published in the blockchain, without the need to publish the document itself, thereby preserving the document's privacy.

The possibility to verify and validate credentials on the spot, which a blockchain allows for, may **reduce bureaucratic procedures** that would otherwise have taken a lot of time for education institutions, employers, graduates and jobseekers. Beyond that, it may **reduce the risk of social (and educational) exclusion for individuals who originate from conflict areas,** such as specific cohorts of migrants and refugees. In theory, the use of a blockchain system can **allow these individuals to keep and manage their identities and records, such as their academic transcripts, certificates, and formal and non-formal learning activities.** In addition, the principle of tamper-resistance of such records in a blockchain enables them to be trusted by interested parties.

As another possible application, the interest of the UK's Open University (OU) in blockchain goes beyond facilitating digital certificates to students by looking into how the university can help graduates get the most value out of their degrees to improve their financial and social conditions – hence the focus on **micro-accreditation via badges.**

### BOX 10. Badges and micro-accreditations[55]

In the UK, the OU's experiments with blockchain started with the identification of a clear value in modular courses, and in smaller or 'bite-size' chunks of learning which gradually add up to a specific number of credits leading to a qualification. In such a context, micro-credentials are important in the sense that a regular student does not need to wait for six years to see a certificate for their studies for the first time. The benefits of having badges on a blockchain include the fact that students can make the badges available to employers, enhancing their employability, while employers can reduce their hiring costs since it becomes easier to search for, find and verify potential candidates with the right profile. If candidates (such as OU graduates) are accessible via a blockchain-based database as a trustworthy environment for verifying credentials, this potentially both eases and speeds up the recruiting process. To further facilitate OU graduates in their search for suitable jobs, the university is also collaborating with two start-ups in London (similar to LinkedIn) and with a reputable recruitment agency. When an employer is interested in recruiting a graduate, the OU is actioned to validate her or his certificate. The OU's signature is then put on to the respective blockchain.



The challenge is that **only by scaling up collaboration will this potential become a reality.** There must be collaboration among all the stakeholders involved: students, higher education institutions, governments and the private sector. In this sense, the EU-funded project QualiChain[56] is targeting the creation, piloting and evaluation of a decentralised platform for storing, sharing and verifying education and employment qualifications, focusing on the potential of blockchain technology.

General claims by the blockchain in education research community suggest that education systems can expect to experience an era in which it will be possible for students to have full control over their data, academic records, certificates, transcripts, course work and assessment. Such a level of individual control over her or his own data is often referred to as a **'self-sovereign identity'.** It means that, over time, students will no longer depend on various services typically provided by higher education institutions. Thus, from this perspective, it is expected that higher education institutions will have to constantly reinvent themselves to keep up with this rapidly changing world, driven by advances in disruptive technologies, such as blockchain. Higher education institutions must also rethink their purpose and update their vision more often.

# SUMMARY AND CONCLUSIONS

## Key insights

This report underlines a series of opportunities and challenges across sectors brought by blockchain technology, which may introduce significant changes in our industry, economy and society. We offer a summary of key insights collected from our analysis of blockchain technology and its applications across sectors.

### How blockchain works

**Blockchain is a tamper-resistant and time-stamped database (ledger) operating through a distributed network of multiple nodes or users.** It is, however, a particular type of database. Transactions between users do not require intermediaries or trusted third parties. Instead, trust is based on the rules that everyone follows to verify, validate and add transactions to the blockchain – a 'consensus mechanism'.

Blockchain is based on a particular combination of key features: decentralisation, tamper-resistant, transparency, security and smart contracts.

The lack of a central entity controlling the system creates strong resilience against single point-of-failure flaws. Since it is extremely difficult to change or delete the record of transactions, in this sense the **records on a blockchain are tamper-resistant.** In public or open blockchains **all transactions are transparent and visible. All transactions are time-stamped** – that is, data such as details about a payment, a contract, transfer of ownership, etc. are linked publicly to a certain date and time. And **smart contracts enable the terms of agreement between parties to be executed and enforced without the need for human coordination or intervention.**

However, **a number of challenges remain unresolved,** such as the **limited scalability and performance** of public blockchains, mainly related to the low volume of transactions, or the **high energy consumption** when deploying current PoW consensus mechanisms. Other threats can arise from **potential collusion** from a majority of participants which could overrun the network (51 % attacks), or from the high dependency of running the network on a limited number of participants. A major source of security vulnerability also lies in the **added responsibility for key management,** which can be as simple and serious as losing a phone or a back-up of the credentials.

Another key issue that needs further research is **how to safeguard personal, sensitive or confidential data.** Transparent data on a blockchain might be a problem when specific data sets are not meant to be publicly available, or need to be changed due to errors, inaccuracies or other problems in the original data entry. Potential conflicts between specific blockchain architectures and the EU's GDPR warrant a wider debate.

### Scanning blockchain ecosystems

To a certain degree, the hype around blockchain technology has been influenced or shaped by a spike in interest from financial institutions since 2014. However, while more well-known applications in the financial sector were under development, **blockchain's broader potential for other sectors increasingly came to the fore.** At the moment, a number of initiatives and pilots are ongoing which means much of blockchain's potential has yet to be fully tested. For instance, recent analyses of its actual economic impact have sent mixed signals.

Nevertheless, blockchain is now o**ne of the technologies which is anticipated to have a profound impact over the next 10-15 years,** backed in the short term by upward forecasts for investment. This is visible, for instance, on how **the attention of investors worldwide has shifted to blockchain companies since 2009.**

The rise of blockchain is witnessed by both the **sharp growth in blockchain start-ups and the volume of their funding. Massive funding started in 2014 with EUR 450 million and rapidly increased to EUR 3.9 billion in 2017 and over EUR 7.4 billion in 2018. In 2017, the amount of invested capital grew at an unprecedented scale** due to the **explosion of ICOs and venture capital investments** which continued at a high level in 2018.

There is **strong competition from the USA and China,** as they now appear to lead in terms of blockchain start-ups. **The UK has a key role in Europe** both in terms of numbers of blockchain start-ups (hosting almost half of them), and in funding (attracting about 70 % of EU investments). A broader look at international players shows **Switzerland and Singapore displaying particular dynamism followed by Japan and South Korea.**

## Blockchain in the EU policy context

The growth and increasing attention to blockchain technology has not gone unnoticed at EU policy level. The main focus was initially placed on the **emergence of crypto-assets and virtual currencies such as Bitcoin.** In November 2016, the EC, in collaboration with the EP, set up a horizontal **task force on FinTech with a dedicated group on DLTs,** which was followed by a public consultation in the following year and the FinTech Action Plan in 2018.

Blockchain, as one of the breakthrough technologies with a huge potential impact for other sectors, has also been publicly recognised by European institutions, with evidence-based research projects such as #Blockchain4EU: Blockchain for Industrial Transformations. This project was carried by the JRC in support of DG GROW as a forward-looking socio-technical exploration of existing, emerging and potential applications based on blockchain and other DLTs for industrial sectors (Nascimento, Pólvora and Sousa Lourenço, 2018).

Several strategies oriented towards blockchain's cross-cutting effects are now being explored across the EC. Amid its recent efforts, **the EU Blockchain Observatory and Forum, the EBP and the Anti-Counterfeiting Blockathon Forum** stand out as key initiatives in close cooperation with stakeholders from industry, start-ups, governments, international organisations and civil society.

A range of **calls, research programmes and funding for third parties** is also at the core of EC support for experimentation and innovation. It includes, for instance, a call in 2018 on 'Blockchain and Distributed Ledger Technologies for SMEs', an EIC Horizon Prize for 'Blockchains for Social Good', and the Pilot Project '#DLT4Good: Co-creating a European Ecosystem of DLTs for Social and Public Good'. The latter is being developed by the JRC in collaboration with DG CNECT and the support of the EP. It is centred on research and experimentation for the development and scale-up of DLT solutions suited to specific challenges of public and third-sector organisations at local, regional, national or supranational levels.

A number of EC services are conducting, starting or reflecting on **exploratory activities using**

**blockchain as possible ways to improve and support the execution of core EC processes and policies.** Such internal explorations or pilots are targeted, for example, at the accessibility of regulated information; real-time reporting; management of identities; notarisation services; and monitoring the movement of goods.

The EP is also actively engaged in past and ongoing discussions about the cross-sectorial potential of blockchain, following its first **Resolution on virtual currencies** that spurred the setting up of the FinTech task force. Since then, the European Parliamentary Research Service has published reports and other materials on the topic. In addition, **two Resolutions – 'Distributed Ledger Technologies and Blockchains: Building Trust with Disintermediation', and 'Blockchain: A Forward-Looking Trade Policy'** – were discussed and approved in 2018.

## Transforming financial systems

As of February 2019, there are more than 2 000 cryptocurrencies (Bitcoin being the most well-known). **Unlike the so-called fiat currency, the value of most cryptocurrencies is not supported by the status of legal tender.** Instead, it is determined by the trust each person has that the underlying technology (blockchain) will not allow double spending, will not be debased, but will be accepted as a means of payment by other economic actors.

The **absence of a monetary authority and of a lender of last resort, however, exposes most cryptocurrencies to high volatility in the face of speculative activities.** It also makes them potentially harder to recover from crises, and exposes them to a long-term deflationary dynamic.

Blockchain activity in finance has remained very strong, with the development of new product classes hybridising cryptocurrencies and DLT-supported fund-raising: **ICOs.** These offerings are becoming significant **fund-raising venues for businesses and start-ups** in particular, as an alternative to formal financing systems. However, **ICOs currently carry important risks.** Such risks arise from the uncertainty of the applicable regulatory framework for ICOs and crypto-asset markets, the lack of financial consumer-protection safeguards, and limitations in the structuring of ICOs and operational risks related to DLTs.

Traditional financial intermediaries have shown great interest in this technology. **Blockchain and DLTs are promising to lower the costs associated with the entire life cycle of a financial instrument** (issuance, trading, settlement, etc.) while simplifying the process of issuing and significantly reducing the clearing and settlement time. Other **successful implementations include a substantial reduction in payment systems' transaction costs.** For instance, effective benefits in cross-border payments are related to real-time reporting and the update of positions, liquidity management, the complete traceability of transactions, and simplified reconciliation across accounts.

However, in most cases, the technology is either not sufficiently well developed to be broadly adopted or is still limited to small subsets of participants. Beside **performance and scalability,** other technical challenges remain regarding **integration with legacy infrastructures or standardisation and interoperability** between different systems. For example, regulatory challenges (Blandin et al., 2019) include the **validity and enforceability of smart contracts;** the nature and financial **classification of tokens; consumer and investor protection;** enforcement of anti-money laundering requirements; and the overall **compliance with securities law.**

## Transforming industry, trade and markets

Blockchain technology is expected to bring a series of benefits to a number of industrial sectors, firms and businesses already experimenting with the technology, or which may soon see their sector or activities impacted by its existence. For instance, **blockchain-based systems could facilitate interactions in global and distributed supply chains between untrusting actors,** including producers, retailers, distributors, transporters, suppliers and consumers. **Traceability and quality control covering how products are grown, stored, inspected and transported – i.e. from the farm to fork,** could enhance accountability for all those involved. **Proof of origin and compliance with environmental rules, organic labelling, fair trade** and other characteristics could help consumers to make informed decisions and steer companies towards more sustainable business models.

In additive and subtractive manufacturing, a blockchain could also serve as a **tamper-resistant record of digital file ownership,** and help to **prevent unauthorised use, theft and infringements.** In the creative industries, it also has the potential to implement **fairer ways of compensating owners and creators** through pay-per-usage, micropayments or automatic payment distributions.

In energy communities and peer-to-peer energy trading and pilots, **smart contracts are automatically managing supply-and-demand flows** towards the optimal use of available energy. Microgrid energy markets could be supported whereby individual customers trade locally produced renewable energy directly with others in their communities with (near) real-time pricing.

However, a number of key challenges lie ahead. Blockchain could support the use of digital data across sectors in **close combination with other digital technologies,** such as IoT, AI, robotics, or additive and subtractive manufacturing. But it is still uncertain how that convergence can actually happen, taking into account the **cost of integration or migration,** for example. **Interoperability between different systems,** blockchain or non-blockchain, is also key. It is also foreseen that ways of creating value and conducting transactions will be improved by faster, cheaper and more reliable mechanisms enabled by blockchain across industries and businesses. However, the **feasibility of new business models and the set of necessary incentives needed for players** to operate in open and decentralised ecosystems needs to be further tested.

Furthermore, regulatory constraints include issues of **applicable laws and jurisdictions for decentralised networks; reliable rules and definitions for smart contracts; and data protection and privacy safeguards.**

## Transforming government and the public sector

The benefits of blockchain technology for the public sector are the ability to provide **tailored services for specific citizens, greater trust in governments and improved automation, transparency and auditability.** Significant incremental benefits can be achieved in some areas by using blockchain technology for the provision of public services. This can range from **more security (enhancement of data integrity, tamper-resistant and consistency between organisations), to efficiency gains (lower operational costs, reduced processing time, less paper and human-labour-intensive processes).**

For instance, a **government-issued identity on a blockchain** can generate time and cost savings for citizens, businesses and public administration in terms of setting up, managing and accessing identities for specific services. **Allocation of public benefits, such as pensions, grants, subsidies or other funds,** can benefit from a decentralised network supported by blockchain to manage transactions without relying on additional third parties or intermediaries. **In education,** blockchain can be used to register digital credentials, thereby enabling the immediate verification and validation of these credentials and, at the same time, **reducing bureaucratic procedures** for education institutions, employers, graduates and jobseekers.

In these and other cases, blockchain functionalities, such as **workflow automation and shared database** (as a single source of truth for all the different parties), can be leveraged to generate significant **efficiency gains in settling multi-party transactions and reducing uncertainties among agents.**

However, until now, and in many cases, **blockchain is neither transformative or even disruptive for the public sector,** as it is often portrayed. Blockchain systems neither provide for the disintermediation of organisations nor replace any existing public institution systems involved in the provision of services.

Blockchain still needs to be integrated with **legacy systems** in order to provide, for the most part, additional new functionalities offering greater assurances for citizens. This technology also still relies on **inputs from centralised or government-owned systems** as regards the provision of property details, for example, or to link to specific natural or legal persons. Moreover, there are doubts about how the external consistency of electronically submitted statements could be ensured, without and outside an arbiter.

The scale and complexity of current public services go beyond current technological blockchain developments. In particular, the **large volume of transactions to be processed with smart contracts** constitutes a major challenge. Ultimately, the adoption of blockchain technology also relies on the **ability to set up, scale up and maintain collaboration between many different stakeholders.**

## Paths ahead

Blockchain now stands as a fast-moving field, often marked by a clouded mixture of high expectations and ongoing experimentations. Beyond the topics explored throughout this report, new issues are now emerging or coming to the fore that could be crucial to grasping other potential impacts of blockchain at policy, economic, social, technical, legal or environmental levels.

While blockchain technology is moving forward dynamically, additional knowledge is still needed to better understand not only its core, but also the floating boundaries surrounding its potential. This will help us to be better prepared to respond to some of the pressing issues policymakers will face tomorrow beyond those that have already made an appearance.

Alongside the strong signals we observed when scanning through present and near-future horizons for blockchain in specific sectors, weak signals are also emerging on longer-term horizons that pinpoint new dimensions of activity. Thinking about the paths ahead for blockchain, we believe it is crucial to start reflecting upon a selected few to avoid missing upfront the knowledge value of such signals and what they expose.

### Trust and governance

Blockchain has the potential to reframe what 'trust' means among individuals, groups, institutions or orga nisations. For some, trust or rather the lack of trust in people and organisations (seen as fallible and corruptible), could be replaced in favour of trust in blockchain architectures that could execute all transactions autonomously and neutrally. But it is **unlikely that intermediaries will disappear or that trust will simply be established through blockchain's technical protocols.**

Instead, **blockchain as a technology is in a complex interplay with economic, cultural, social, political and institutional dimensions** (Catlow et al., 2018; Brekke, 2019). When it comes to smart contracts, for instance, gaps between the legal and technical language require (or might always require) the presence or intervention of lawyers and legal experts with both an overall and precise knowledge of relevant legal frameworks (Al Khalil et al., 2017).

Although fraught with cumbersome and costly processes, third parties like governments might still be needed to define equal conditions for participation in society and economy, to decide on responsibility and liability, enforce rules and settle disputes, or to provide guarantees and protection under the law.

More discussion is needed on the **conditions for trust when developing and deploying blockchain technology.** Transformation of the roles of traditional intermediaries or third parties, together with a rearrangement of interactions between individuals, groups and companies, call for a **scrutiny over governance mechanisms that will run and enable such blockchains.** For example, this concerns a formal or informal definition of **who does what and when in a specific blockchain network (users, validators, regulators, …) and associated levels of responsibility and accountability** (Lapointe and Fishbane, 2018).

## Decentralised coordination

Blockchain is discussed as a **new institutional technology** for decentralised coordination and governance of economic and social interactions (Davidson et al., 2016; Bodó and Giannopoulou, forthcoming). Within this perspective, blockchain competes with other coordination institutions such as firms, markets and governments.

Decentralised governance can move the full control of governments over transactions towards **shared control distributed among many participants.** Citizen-controlled identity, automatic enforcement of regulations via smart contracts or location-agnostic tamper-resistant voting may shift decision-making to citizens and enhance their sovereignty.

Blockchain may also introduce **more 'decentralised', 'distributed', 'collaborative' or 'peer-to-peer' processes for economic organisation.** We have already witnessed the disruptive effects of similar models under 'platform economies' or 'sharing or collaborative economies' (Esser et al., 2016; Bock et al., 2016; Codagnone et al., 2016).
Here, blockchain could boost the development of new innovation models and sources of growth, sometimes at the expense of established businesses. But it could also enable diverse sources of value creation, revenue distribution and the overall **rebalancing of asymmetric relationships between economic actors.** Disintermediation could also mean spurring more dynamic models whereby many different actors, individual or collective, can create, sell, buy or be compensated for their digital assets.

In the nearer future, the boundaries might revolve around **new types of economic and social institutions executing blockchain rule systems,** like smart contracts, towards polycentric and common pool resources governance. Some are already experimenting with decentralised autonomous organisations, or DAOs, which can own, exchange or trade resources and interact autonomously with other humans, devices, organisations or other DAOs, in a kind of algorithmic decision-making (Buterin, 2014; Mougayar, 2015).

## Crypto-economies

The **future proliferation of parallel or unregulated economies,** with little connection with mainstream economies, could be more significant than pockets of criminal activity, fraud or scams. Blockchain could enable the spread of transnational, non-territorial and permission-less innovation for entrepreneurs and business operations that circumvent any regulatory or political supervision, for instance in the form of 'crypto-anarchies' or 'crypto-secession' (Macdonald et al., 2016).

One ground-breaking development could probably be around the notion of **tokens within the present and future scenarios of crypto-economies.** Going beyond its financial connotation, a 'currency' or more generally a 'token' or 'digital asset' in a blockchain system can be understood as a multipurpose unit of value used in particular business models or economic systems (Mougayar, 2017). For instance, in different blockchain systems, a token gives special access to a service or product (for instance, cloud storage), represents voting rights within a group or community, and/or compensates participants for their time, work, reviews or other contributions, everything within the network.

Crypto- or token-based systems can have consequences for the **coordination of behaviour and interactions between individuals, groups, communities and organisations.** That is, they raise questions about possible **new distributed economies or market places,** gathering different actors under shared goals. In this respect, the emerging 'crypto-economics' field brings together economics, computer science and behavioural sciences to study individual decision-making and strategic interactions in such ecosystems.

## Self-sovereign identity

Blockchain could offer alternative mechanisms to implement identity management or the **principle of self-sovereignty that could allow individuals to keep and manage their identities and records in a blockchain.**

Depending on its design, blockchain systems could potentially enable **decentralised and privacy-friendly solutions.** At the very minimum, blockchain architectures can offer pseudonymisation and not full anonymisation, so in most cases additional layers of encryption and/or obfuscation are required to conceal certain details about transactions or confidential data (De Filippi, 2016). It is also possible to give authorisation to data only to specific or trusted parties, or to revoke access at specific times. This could enable faster and more secure identity management processes, and greater overall control over the disclosure and selective sharing of data. Decentralised solutions for such purposes are currently under development and subjected to critique (Narayanan et al., 2012). For example, there are several ongoing projects and initiatives working on **new regimes of citizen-controlled and self-sovereign digital identity** (Financial Times, 2017; Symons et al., 2017) based on **distributed, open and modular architectures for managing online identity and data** in real-time and confidential ways.

As an additional layer, it is relevant to further assess **how blockchain could work in combination with other distributed identity and authentication systems** in line, for instance, with the eIDAS Regulation on the use of electronic identification and electronic Trust Services, namely electronic signatures, electronic seals, time stamp, electronic delivery service and website authentication, to enable secure and cross-border electronic interactions between businesses, citizens and public authorities.

## Interoperability and standardisation

Whatever blockchain solutions will be developed in the coming years, interoperable protocols are at the core of ongoing efforts so that different blockchain products and services do not end up closed and unable to communicate with each other.

Interoperability is being pursued through **standardisation working groups at international and supranational level. Some argue that such standardisation will be essential to harmonise its applications, 'de-niche' the technology and enable cross-industry adoption.** Others argue that **premature adoption might validate still untested technologies and/or privilege solutions** from influential companies and lock out new players.

On the one hand, challenges for ongoing standardisation activities concern the **fragmented and nascent body of conceptual and practical knowledge on blockchain.** On the other hand, they are related to the **lack of integration of blockchain developer communities** which tend to be more disconnected from these activities or overshadowed by larger technological or commercial members.

**The dangers of platform or vendor lock-ins** could potentially be minimised by more inclusive processes which, in practice, would allow newer or smaller players to participate in a meaningful way, taking into account their limitations in time, capital and human resources. In this respect, current multi-stakeholder governance procedures for the development of standards could be further discussed and improved in order to fulfil the **guiding principles of openness, transparency and consensus.**

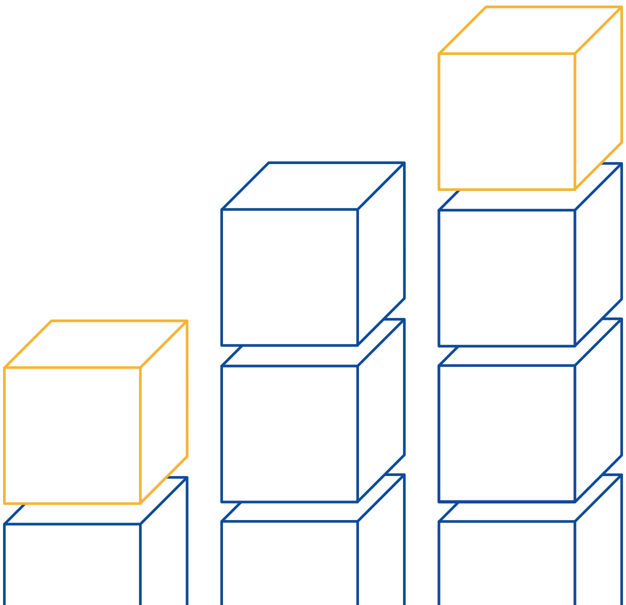
## Data management and governance

Managing digital data has become a central part of most businesses and industries and will most probably intensify in the foreseeable future. **Who processes, stores and owns data, how and for what purposes,** are or will become crucial questions for any organisation. As a tamper-resistant ledger, a blockchain could provide more mechanisms to guarantee data authenticity and reliability (Lemieux, 2016).

Yet blockchain does not offer complete solutions for ensuring the accuracy, consistency or validity of data throughout its entire life cycle. For instance, issues can arise from **the quality of the data being entered, processed and stored in a blockchain** – that is, if data is incorrect, invalid or complete. Blockchain technology only records and verifies the data as it is introduced and by consensus of those participants or nodes involved, with no guarantees or fact checking on its veracity.

**The stability and continuity of blockchain technical architectures** might also be a problem. For instance, there is a risk that records from previous blockchain systems ('forks') may no longer be preserved, updated or maintained and may create confusion throughout the network about a legitimate and new version of a record.

**Organisations must assess their resources to establish trusted digital repositories** and guarantee additional technical, policy and institutional capacity for **proper archival storage, data management, access to and the overall preservation of records.**



# ENDNOTES

1 *https://lightning.network*

2 *https://raiden.network*

3 His, her or their identity is still unknown and remains a source of regular speculation, see, for example, recent news stories: *http://www.newsweek.com/2014/03/14/face-behind-bitcoin-247957.html*; *https://www.nytimes.com/2015/05/17/business/decoding-the-enigma-of-satoshi-nakamoto-and-the-birth-of-bitcoin.html*; *https://gizmodo.com/this-australian-says-he-and-his-dead-friend-invented-bi-1746958692*.

4 For a list of all active cryptocurrencies, see: *https://coinmarketcap.com/all/views/all*.

5 Agreement ledger*, Altcoin*, Attestation Ledger*, Bitcoin*, Block cipher*, Block height, Block reward*, Blockchain Use Case*, Blockchain*, Central ledger*, Chain linking, Consensus Mechanism*, Consensus Process*, Consortium Blockchain*, Cryptoanalysis, Cryptoasset*, cryptocoin*, Cryptocurrenc*, dApp*, Decentralized Autonomous Organization*, Digital Commodit*, Distributed Consensus, Distributed Ledger Technolog*, Double Spend*, Doublespending, Ether, Ethereum*, EVM, EVM code*, Full Node*, Halving, Hash Cash*, Hash Rate*, Hashcash*, Hashrate*, Hyperledger, ICO, Initial Coin Offer*, Ledger Replication*, Litecoin*, Multisig*, Permissioned Blockchain*, Permissioned Ledger*, Permissionless Blockchain*, Permissionless Ledger*, Private Ledger*, Proof of Authority, Proof of Stake, Proof of Work, Public Ledger*, Self Souvereign Identit*, SHA 256, Smart Contract*, Soft Fork*, Softfork*, Solidity, Stream Cipher*, Tokenless Ledger*, Transaction Block*, Unpermissioned ledger*, Zcash*.

6 A new start-up is registered in the Venture Source database upon receiving its first financial deal. This event may happen several months after the company has been established. Moreover, financial deals are usually disclosed with a time lag. To mitigate these effects, the data covers the period 2009-2018 but was collected in May 2019. However, the results for 2018 may be prone to minor changes in the coming months.

7 This classification covers 28 categories of economic activity as reported by Venture Source: Aerospace and Defence; Agriculture and Forestry; Biopharmaceuticals; Business Support Services; Communications and Networking; Construction and Manufacturing; Consumer Information Services; Electronics and Computer Hardware; Financial Institutions and Services; Food and Beverage; Healthcare Services; Household and Office Goods; Information Services; Machinery and Industrial Goods; Materials and Chemicals; Media and Content; Medical Devices and Equipment; Medical Software and Information Services; Non-Renewable Energy; Personal Goods; Renewable Energy; Retailers; Semiconductors; Software; Travel and Leisure; Utilities; Vehicles and Parts; Wholesale Trade and Shipping.

8 Figures on investment levels given above are underestimated for two reasons. First, in total, only 65% of deals of blockchain firms reported in the Venture Source database detail an amount of funding. Importantly, nondisclosure ratio differs between major blockchain players. For the EU and the US firms only 22% of deals do not report amounts, while for Chinese companies as much as 62% deals have undisclosed amounts. Second, Venture Source database focuses primarily on private equity funding. For this reason the coverage of non-equity based deals, such as initial coin offerings, is limited. In particular, several large ICOs that took place in 2018 are not covered.

9 Disclaimer: The figures related to initial coin offerings should be taken with care. The amount of ICO funding, presented in section 2.2, is underestimated due to incomplete coverage of these deals in Venture Source database. See also footnote 6 for more details. Section 4.2 provides a separate analysis of initial coin offerings, based on more complete data from Coinschedule.

10 As is shown later, the majority of deals in blockchain start-ups took place in 2017-2018. Average time-to-exit from venture capital investment is six to eight years.
11 *https://www.eublockchainforum.eu*
12 *https://ec.europa.eu/digital-single-market/en/news/european-countries-join-blockchain-partnership*
13 *https://ec.europa.eu/digital-single-market/en/news/study-opportunity-and-feasibility-eu-blockchain-infrastructure*
14 *https://www.iso.org/committee/6266604/x/catalogue/p/0/u/1/w/0/d/0*
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17 *https://www.cencenelec.eu/news/articles/Pages/AR-2017-012.aspx*
18 *https://euipo.europa.eu/ohimportal/en/web/observatory/blockathon*
19 Details on winning teams and solutions: *https://euipo.europa.eu/ohimportal/en/web/observatory/blockathon/finalists-and-winners*
20 *https://euipo.europa.eu/knowledge/course/view.php?id=3038*
21 *https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/innosup-03-2018*
22 *http://www.blockchers.eu*
23 *https://ec.europa.eu/research/eic/index.cfm?pg=prizes_blockchains*
24 *https://blogs.ec.europa.eu/eupolicylab/portfolios/dlt4good*
25 *https://ec.europa.eu/digital-single-market/en/blockchain-technologies*
26 *https://ec.europa.eu/programmes/horizon2020/en/h2020-section/leadership-enabling-and-industrial-technologies*
27 *https://dcentproject.eu*
28 *https://decodeproject.eu*
29 *http://www.myhealthmydata.eu*
30 *https://ec.europa.eu/digital-single-market/en/news/information-day-horizon-2020-blockchain-distributed-ledger-technologies-topics-and-fintech*
31 *http://europa.eu/rapid/press-release_MEMO-18-6690_en.htm*
32 *https://eftg.eu*
33 *https://www.ey.com/en_gl/assurance/why-europe-is-open-for-business*
34 *https://steemit.com/utopian-io/@utopian.tasks/how-to-build-a-private-steem-blockchain-european-financial-transparency-gateway-steem-bounty*
35 *https://steemit.com/blockchain/@sorin.cristescu/eu-citizens-blockchain-in-a-box*
36 A video showcasing the demonstrator is available here: *https://www.pwc.be/fismablockchain*
37 *https://steemit.com/eftg/@pstaiano/the-european-financial-transparency-gateway-eftg-pilot-project*
38 *http://www.itone.lu/actualites/blockchain-and-data-virtualisation-european-commission*
39 A video showcasing the EMCS PoC is available here: *https://youtu.be/qsmo7VOqATI*
40 *https://mag.wcoomd.org/magazine/wco-news-87/digitization-ata-carnets*
41 The PoC demonstrator is available here: *https://poc.webexpert.ch*
42 The number of confirmations is not a standard value but rather depends on the trust the merchant puts in each transaction. Six confirmations, taking around an hour, are generally considered secure enough in Bitcoin, although many merchants would even accept two or three as the risk involved in a low-value transaction is low and is not worth waiting for more confirmations.
43 The 5th AMLD also provides a definition for virtual currency as 'digital representation of value that is not issued or guaranteed by a central bank or a public authority, is not necessarily attached to a legally

established currency and does not possess a legal status of currency or money, but is accepted by natural or legal persons as a means of exchange and which can be transferred, stored and traded electronically' (Directive (EU) 2018/843).

44 More information about Bloodchain: *https://blogs.ec.europa.eu/eupolicylab/blockchain4eu/bloodchain*

45 See, for instance, recent EUIPO Blockathon: *https://euipo.europa.eu/ohimportal/en/web/observatory/blockathon/challenges/customs-authority* and *https://euipo.europa.eu/ohimportal/en/web/observatory/blockathon/challenges/logistics-operator*

46 See *https://www.winefraud.com*

47 More information about Vantage Point: *https://blogs.ec.europa.eu/eupolicylab/blockchain4eu/vantagepoint*

48 See *http://www.moog.com/news/corporate-press-releases/2018/STAerospaceCollaborate3DPrinting.html* and *https://www.automationworld.com/blockchain-coming-manufacturing*.

49 More information about Gigbliss: *https://blogs.ec.europa.eu/eupolicylab/blockchain4eu/gigbliss*

50 See, for example: *http://open-music.org/blog/2016/6/6/why-us-why-now*

51 See *https://blog.ujomusic.com/welcome-back-1addcc06bcc6*

52 More information about Gossip Chain: *https://blogs.ec.europa.eu/eupolicylab/blockchain4eu/gossipchain*

53 More information about Care AI: *https://blogs.ec.europa.eu/eupolicylab/blockchain4eu/careai*

54 Other private cases are currently under development, such as Alastria, Jolocom and Sovrin.

55 Based on an interview with Prof. Dr John Domingue (Open University UK), conducted in September 2018.

56 *https://qualichain-project.eu*

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