Financing Climate Futures

RETHINKING INFRASTRUCTURE

Blockchain Technologies as a Digital Enabler for Sustainable Infrastructure

CASE STUDY

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BETTER POLICIES FOR BETTER LIVES

Financing Climate Futures

RETHINKING INFRASTRUCTURE

Governments recognise that scaling up and shifting financial flows to low-emission and resilient infrastructure investments is critical to deliver on climate and sustainable development goals. Efforts to align financial flows with climate objectives remain incremental and fail to deliver the radical transformation needed. The OECD, UN Environment and the World Bank Group, with the support of the German Ministry of Environment, Nature Conservation and Nuclear Safety, have joined forces under a new initiative – *Financing Climate Futures: Rethinking Infrastructure* – that provides a roadmap to help countries make the transformations in their infrastructure, investment and finance systems that are needed to make financial flows consistent with a pathway towards a low-emission, resilient future.

For more information on *Financing Climate Futures: Rethinking Infrastructure* visit: oe.cd/climate-futures

Blockchain technologies as a digital enabler for sustainable infrastructure

Embracing new technologies that could enable drastic reductions in GHG emissions will be key to delivering low-emissions pathways for growth, but it is not always obvious what the big breakthroughs will look like. This report looks at how blockchain technology can be applied to support sustainable infrastructure investment that is aligned with climate change objectives. It focuses on three key points: the financing of infrastructure initiatives, the creation of visibility and alignment of climate action, and the provisioning of awareness and access for institutions and consumers. Blockchain technology can address these challenges by creating new ways of raising capital, providing transparency through an immutable record of transactions, and establishing new inclusive market mechanisms.

DISCLAIMER

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This paper is a contribution to *Financing Climate Futures: Rethinking Infrastructure*, a joint initiative of the OECD, UN Environment and the World Bank Group, to help countries deliver on the objective of making financial flows consistent with a pathway towards low-emissions and climate-resilient development.

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Blockchain Technologies as a Digital Enabler for Sustainable Infrastructure

Embracing new technologies that enable drastic reductions in greenhouse gas (GHG) emissions will be crucial to mitigate the effects of climate change, but it is not always obvious what the big breakthroughs will look like. It is likely that many technologies, operating in concert, will be needed to tackle the complexity of the problem at hand. Investment and innovation in energy storage, renewable energy generation, materials, transportation services, agricultural sciences, and digital technologies are some of the areas that are vital to the low-carbon transition.

A number of digital innovations are emerging in the global economy which offer the potential to transform how systems operate by making infrastructure, manufacturing, trade, and agriculture more connected, intelligent, and efficient. One of the benefits of promoting digital innovation is that it could lead to further innovations, unlocking unforeseen possibilities. This is particularly true in infrastructure services as the potential for innovation within the sector is large. This report explores how innovation and specifically distributed ledger technologies (DLT), such as blockchain, integrated with other technologies like the internet of things (IoT) and artificial intelligence (AI), could accelerate a cost effective transition in key infrastructure services.

When thinking about blockchain, carbon neutrality is not the first thing that comes to mind. Bitcoin, blockchain's first application, is widely known as an environmental polluter, consuming massive amounts of energy and emitting vast amounts of CO_2 in order to validate transactions and sustain the network. However, concerns of this nature hold true only for specific applications of the underlying technology. Section 1.3 describes how blockchain can be deployed in an energy-efficient way. This report suggests that blockchain technologies and their underlying concepts have the potential to deliver sustainable infrastructure by unlocking opportunity along the infrastructure value chain.

In principle, blockchains or DLT, terms which are often used interchangeably, can be used for recordkeeping and the transfer of value (via cryptocurrencies or otherwise) without requiring a trusted central entity to maintain a database and validate transactions. Instead, these functions are accomplished by decentralising the network in which data is stored and by providing a validation mechanism through which all participants in the network have an immutable single "source of truth". The so-called "smart contracts" which are enabled by blockchain technology allow for the automated execution of a transaction when one or more preconditions are met, thus providing a potential for significant efficiency gains. Physical and digital assets can be represented as "tokens" of value on the shared distributed registries, allowing the tokens to be directly traded among network participants. In essence, these core capabilities allow for the use of cryptocurrencies (e.g. Bitcoin, Ether) as well as tokenised digital records (e.g. property rights, physical property rights) in the context of the infrastructure lifecycle, from financing, and procurement, through tendering and operations.

The G20's 2018 *Roadmap to Infrastructure as an Asset Class* focuses on ways to improve the overall investment environment for infrastructure (G20, 2018). This work combined with OECD work on infrastructure, data and performance measurement, and finance, yields several key points that are important in the blockchain context:

- Building **greater standardisation in infrastructure** across the value chain, including contractual standardisation and financial standardisation. Greater standardisation of contracts and documentation in the bidding and procurement stages of the infrastructure project life cycle is critical to reducing their cost and complexity, as well as facilitating their comparability. Greater financial standardisation would reduce investment costs and facilitate allocations by institutional investors into infrastructure investment.
- Stressing the **importance of data** to support well-informed investment decisions in infrastructure. New technologies can be leveraged to support greater data availability and quality, particularly when considering the possibilities of IoT, AI, geospatial (satellite), and blockchain in infrastructure systems.
- Solutions to **manage risks in infrastructure investment** through better transparency, identification, or measurement of risks, along with effective mitigation strategies. In particular, the management of political or currency risks associated with infrastructure could be improved by enhanced transparency, accountability, improved regulatory oversight, and enabling frameworks. Even a small reduction in these risks could have a real impact on investment levels in infrastructure, particularly in developing countries.
- Translating efficiency gains, risk identification and reduction into a **lower cost of capital and more efficient risk charges** for infrastructure assets. Tools such as IoT sensors could provide inputs into more accurate financial and credit risk modelling, using real-time data on asset performance. More accurate revenue and cost forecasting using AI tools that can process large amounts of data could also provide further cost savings.

Yet, infrastructure-related actions taken at the national and sub-national levels present some challenges. First, capacity bottlenecks on sub-national levels restrict the investment opportunities of governments, leading to a financing deficit in infrastructure projects. The participation of investors is also often limited due to misalignments between the financial or risk profile of infrastructure projects and investor demands. Secondly, efforts are often not transparent in regards to their alignment with other entities' actions, or compliance with standards, including environmental, social, and governance (ESG) criteria. Thirdly, in some cases investment decisions are made without consideration to climate impact.

Blockchain can be applied as a digital backbone within infrastructure projects and operations. The technology can help to to increase efficiency and transparency in global infrastructure systems. Although blockchain is regarded as an emerging technology, a plethora of working prototypes and collaborative initiatives targeting the transport, energy and agriculture industries has been developed and established to realise their proposed use cases.

When looking at blockchain use cases for infrastructure (either described in this report as existing initiatives, or in case studies where pilot programmes and testing could be launched), the following aspects emerge as key areas to help facilitate investment:

- Improving access to markets and finance for infrastructure;
- Increasing transparency, standardisation, and the quality of data on infrastructure performance, including financial data, operations, and ESG criteria of infrastructure projects;
- Promoting compliance with standards, such as sustainability standards;
- Improving infrastructure operations, processes, transactions, and record keeping;
- Enhancing technological integration, further productivity gains, and new business models.

Nonetheless, blockchain technology currently faces several challenges. Although many experts anticipate that it will have a wide-reaching impact on daily processes (e.g. cross-border transactions, procurement of energy, e-commerce, food supply chain tracking), a lack of education and knowledge regarding its principles and drawbacks is observed in the market. Moreover, some misconceptions have become engrained in the wider public. New technologies, especially in untested markets, pose risks which need to be compared with benefits. It is therefore essential to increase fact-based knowledge and training of relevant decision makers, in order to realise the technology's potential.

The opportunities and challenges of blockchain technology for sustainable infrastructure are discussed throughout the report. First, the principles of blockchain technology and its relevance for enabling sustainable infrastructure are briefly discussed. Second, the case for the use of blockchain technology in sustainable infrastructure is made, including a selection of blockchain technology's possible applications that may effectively facilitate climate mitigation and adaption measures. Third, a series of original case studies is introduced, drawing on the most important impactful opportunities to address the previously identified obstacles to sustainable infrastructure investment. Fourth, a roadmap for blockchain implementation presents an action plan for bringing ideas to life through proof-of-concept and pilot programmes. The report concludes with implications for policy makers and suggested steps to leverage the technology's value-added.

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Executive summary

Mobilisation of investment in sustainable infrastructure, a key segment of the global economy that drives GHG emissions, is critical for mitigation as well as adaptation efforts in the transition to a low carbon future. Public and private financial flows in infrastructure projects need to be aligned with broader climate objectives and the 2030 Agenda for Sustainable Development, while taking into account countries' investment strategies and circumstances. Infrastructure investment is also a key theme in global fora such as the G20, where policy work increasingly focuses on quality infrastructure to support inclusive growth.

Achieving these goals will require a visionary reassessment of infrastructure systems and services, from their interaction with consumers all the way through operations, financing, construction, procurement and planning. Transportation, energy, and information and communication technology (ICT) infrastructures are essential services which, when built to be resilient and consistent with a low-carbon transition, can contribute to growth and development in a sustainable way. Game-changing approaches are needed to reimagine how this transition could be accomplished, at low-cost and in an equitable way. DLTs, such as blockchain, are emerging technologies that have the potential to improve current processes and systems by acting as a digital enabler across the infrastructure value chain.

Blockchain technology leverages its core competencies of providing transparency, data auditability and privacy, and process efficiency and automation in order to drive the systemic changes needed to deliver sustainable infrastructure. Firstly, the technology can unlock new sources of financing and mobilise existing pledges through establishing new financing platforms. A clear objective is to lower the cost of capital for infrastructure projects, along with improved liquidity, transparency, and expanded access to finance.

Secondly, it can provide global visibility and alignment of sustainability goals and therefore help countries and other stakeholders track data and information on infrastructure projects. Blockchain-enabled platforms are a way to standardise data, assess asset performance, and enhance compliance, which may be further augmented when they are integrated with remote sensors (internet of things), or linked to deep analytics like artificial intelligence application ns.

Thirdly, it can act as a transaction-enabling infrastructure of new market models, which incentivises and increases institutions' and consumers' willingness and ability to contribute to building long-term sustainability, driving also changes within industries to adapt to the shifting demands of consumers.

An array of existing use cases building on blockchain technology that address the challenges facing infrastructure value chains are explored in this report. For further consideration, four original case studies with the highest expected impact for achieving long-term and sustainable provision of infrastructure services are discussed. A roadmap for blockchain implementation and pilot programmes follows the case studies, which include:

- A *decentralised financing infrastructure* enables the full spectrum of investors to invest directly in sustainable infrastructure through a blockchain-based platform, transforming illiquid assets into tradeable digital assets and increasing financing flows for sustainable development. Reducing the cost of capital, transaction costs, and improving liquidity and market participation for sustainable infrastructure projects are the objectives of this case study;
- *Emissions certificate trading systems* can be made more efficient by providing transparency and reliable data through a global blockchain layer. This helps to effectively control quota rules, certificate circulation, promote market integrity, and robust carbon accounting while also automating transactions and increasing overall efficiency;
- A *blockchain-based infrastructure contract management system*, which verifies and tracks the valid and legally binding versions of contracts in infrastructure projects, could immensely improve transparency in current multi-party contract agreements. By adopting such IT systems, involved parties can benefit from certainty of which contract version is valid, and review the conditions at any given time, leading to more streamlined and automated processes;
- By creating an underlying blockchain base protocol layer, *decentralised applications can be built by any organisation to support the governance, alignment and monitoring of various infrastructure standards*. Acting as an open application platform, analogous to Android, a diverse set of enabling functions can be handled on the globally interoperable data infrastructure. Implementing the right measures for global infrastructure-related action (e.g. financing, certification, reporting and compliance, ESG and climate-related disclosures) requires decision makers to have access to genuine, standardised and up-to-date information.

The current state of blockchain adoption in the realm of infrastructure is discussed while weighing its advantages and disadvantages. A prominent limitation of blockchain applications lies in regulatory uncertainty (e.g. a lack of market-based regulations for initial coin offerings (ICOs)), problems of market integrity, and a lack of consumer and investor protection which all need to be addressed in order to build a solid footing for this emerging technology.

Overall, blockchain technology offers potential in building collaborative platforms and network systems, which can help in the achievement of country investment goals, including for the low-carbon transition. However, a number of policy actions are needed in order to facilitate the development of blockchain-based solutions in a safe and fair way. Policy makers should encourage co-innovation and collaboration, support R&D and education efforts (for a full understanding of risks and opportunities) and take initial steps in addressing legal and regulatory issues related to the use of blockchain technology.

As many of these issues reach across borders, the international coordination of policy actions is essential. Initiatives that provide a platform for the international community, such as the OECD Global Blockchain Policy Forum (www.oecd.org/finance/oecd-blockchain-policy-forum.htm) and the OECD Blockchain Policy Centre (www.oecd.org/daf/blockchain), help to drive the exchange of information and experiences. The OECD has also recently launched the *Sustainable Infrastructure Policy Initiative* to pilot the development of instruments, analysis and data related to infrastructure, which will include the role of technology and innovation in driving systemic changes in infrastructure.

1. Overview of blockchain technology

1.1. Blockchain initiatives related to sustainable infrastructure

As with all technological developments, technology usually serves as a means for the purpose and should only be implemented if the technology's respective capabilities address specific needs. In regards to sustainable infrastructure, many conventional technologies (for example cloud computing, automation, traditional ERP systems, etc.) could be leveraged to improve current processes and build transparency between the relevant stakeholders. Pros and cons of different technologies should be considered for each problem or project before deciding on and building solutions. Blockchain is especially suited for problems that require coordination of various parties, where interests might be different, or where secure and immutable exchange of information and value is required.

With this in mind, blockchain could be transformative in changing traditional business models in infrastructure industries towards more customer centric models. Two of the largest infrastructure industries (and emissions intensive), namely the energy and transportation sectors, represent some of the major ecosystems developing applications of blockchain technology.

In the energy sector, a number of initiatives, corporate efforts, and start-ups have emerged in the last two years. Blockchain-based systems and applications are being developed throughout the value chain from generation, transport, distribution, and storage to trading and retail.

One of the earliest technical pilots in the field was the Brooklyn Microgrid in New York City. The project aims to build a peer-to-peer energy exchange, in which citizens trade their self-produced renewable energy with each other (Papajak, 2017). Another example of an early blockchain initiative is the incorporation of the Energy Web Foundation (EWF) as a global consortium of generators, integrated utilities, and related companies such as research institutes, IT service providers and start-ups. In addition to developing a new open-source core technology platform that is purpose-built for the energy sector, EWF has set up several specialised working groups and knowledge exchange forums in order for EWF "affiliates" to accelerate development of blockchain-based applications for certificate of origin markets for green power, demand response programmes, electric vehicle networks, and other application domains.

The transport and mobility sectors have just recently accelerated and increased the breadth of blockchain-related activity. On one hand, the development and piloting of several blockchain-based digital services is increasing, as most auto original equipment manufacturers (OEMs), tier 1 suppliers, and many software firms are working on solutions to current pain points, such as inefficient processes and data sharing. On the other hand, new ecosystems are forming in the sector. In early 2018, an alliance named the Mobility Open Blockchain Initiative (MOBI) was launched. MOBI is aiming to align the activities of its members, in order to strengthen their collaboration and ultimately increase the effectiveness of their blockchain-based systems, building on network effects and standardisation.

Box 1. Market overview and relevance

Since the emergence of blockchain technology in 2008 and up until about 2013, much of the early hype reflected early adopters like avid speculators trying to monetise the high volatility of the cryptocurrency Bitcoin. The hype is arguably still in full swing - the number of blockchain wallet users worldwide amounted to approximately 36 million by the end of April 2019, increasing from around 24 million users in April 2018. Yet, market developments indicate that blockchain technology is gradually moving towards more business-related use cases.

Blockchain is garnering much attention amongst corporate executives, with more than USD 2.45 billion of investment committed worldwide in 2017 and 2018. Prominent examples of big enterprises experimenting and developing blockchain applications include Microsoft, Goldman Sachs, and Maersk. Companies are also increasingly joining consortia in order to explore the potential of DLT. Among executives knowledgeable about blockchain technology, 18% already participate in a consortium, 45% are likely to join one, and 14% are considering forming one. Industry consortia are focusing on developing solutions to their business issues with the help of blockchain technology, whereas technology consortia are focusing on developing use case agnostic blockchain technologies, and are mostly formed by blockchain technology providers. These technology providers drive innovation for consensus algorithms, transaction efficiency, and interoperability across different blockchain platforms. In terms of industry collaborations, EWF, MOBI, B3i and RiskBlock, amongst others, represent the leading initiatives in the energy, mobility and insurance sectors, respectively.

More than 2,500 start-ups have formed, raising just over USD 1.0 billion in equity investments in 2017 alone. However, this number needs to be compared to the USD 21.2 billion that was raised from the beginning of 2018 through the end of October 2018 via 3,252 Initial Coin Offerings (ICOs), a new funding mechanism through which organisations receive funding by issuing coins or tokens on a blockchain (Momtaz et al., 2019, Deloitte, 2017c).

Although blockchain initiatives initially started in the financial services industry, other industries have quickly followed as they gradually identified new opportunities. Use cases have emerged in disparate areas in nearly all industries, from the basics of payments solutions and identity management to more complex uses. Chemical, pharmaceutical, and food companies can track perishable goods and check their preservation status along the chain of custody. Artists and media operators can leverage blockchain technology to manage copyrights and to enable seamless flow of micro-payments for downloads, streaming or licensing –- and the list goes on.

Blockchain technology can also drive the convergence of sectors. By taking the example of mobility as a service (MaaS), otherwise highly isolated industries like the energy and automotive sectors are increasingly collaborating. Given the accelerated adoption of electric mobility and an increased demand of consumers for a seamless journey among transportation elements, the interoperability of infrastructure systems must be increased. Some initiatives have been launched to develop blockchain-based solutions seeking to help

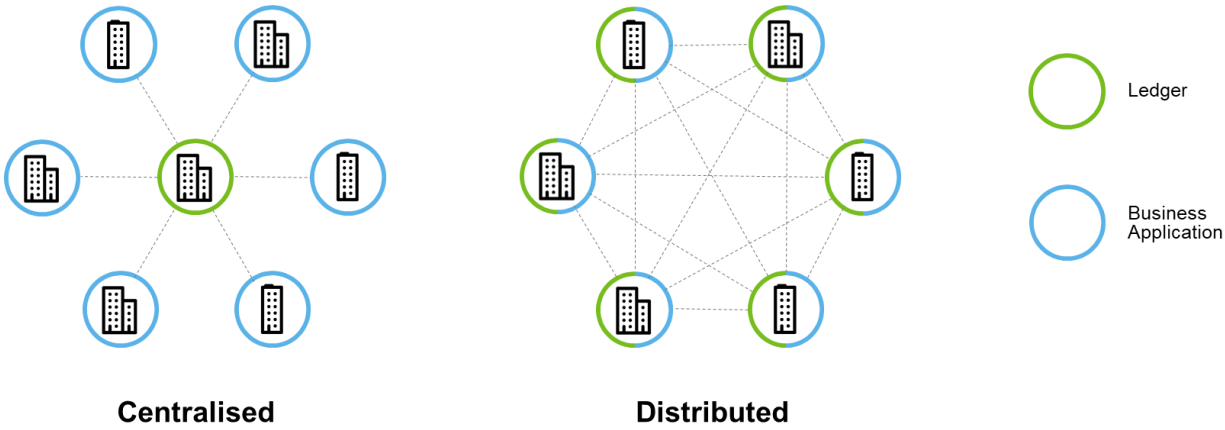
mediate mobility-related transactions, such as booking a shared car, or the charging of electric vehicles (Sümmermann et al., 2017).

Reflecting the worldwide efforts and committed investments, it becomes evident that the technology could play a significant role in future technology and business architecture designs as well as enable novel and efficiency-increasing services. Sections 2. and 2.1 give a detailed overview of the broader implications of blockchain for infrastructure.

1.2. Fundamentals of blockchain technology

distributed ledger technology (DLT) denotes the logic of interconnected digital networks of computers. DLT is the concept of maintaining a shared ledger on a decentralised network, whereby all participants agree on a commonly accepted state of the registry's content (Wright and De Filippi, 2015). Blockchains denote protocols that govern distributed ledgers; therefore, the term is commonly used interchangeably. The transformative potential of blockchain technology lies in its built-in and decentralised trust.

Figure 1. Centralised transactions vs. decentralised transactions



Source: Adapted from "Blockchain @ Media. A new Game Changer for the Media Industry?" Deloitte (2017).

The decentralisation element of DLT creates a system in which all transactions are shared, verified and accepted by all parties, alleviating the need for intermediaries, as depicted in Figure 1. Traditionally, in order to process transactions between two unknown parties, a central authority would be entrusted with the process and would oversee the correct enforcement of transactions (e.g. banks in payment clearing and settlement systems). Although this centralised system usually involves an objective third party to verify and settle transactions between unknown or distrusted parties, it creates dependency on the third party and some level of inefficiency. With blockchain, a common, tamper-proof ledger is held by each party to the network. As all parties have a shared single "source of truth" of the transaction data and agree on its veracity, they do not need an intermediary to validate transactions in the ledger. This could also have an effect on counterparty risk. This type of risk cannot be eliminated by using a distributed ledger, but it can be controlled to some extent as governance principles are agreed upfront and non-adherence to the required steps, e.g. in a business transaction, are not possible without approval by the network participants.

The general concept of blockchains can be illustrated by using the most prominent example – the Bitcoin blockchain. Blocks store data and are propagated to all computer nodes in the network (Swan, 2015). The nature of the distributed registry demands a mechanism to

decide which piece of information is correct and up-to-date. Since all servers participating in the network (so called “nodes”) are able to propose different versions of the next block in the chain, one of the nodes must be chosen to write, validate and seal the block. This process is called "consensus mechanism” and, within the Bitcoin blockchain, includes solving a computational task. There are incentives for participants to perform this computational task. The winner seals the block through a process called hashing, which is the cryptographic term for calculating the fingerprint of a set of data. This fingerprint (“hash”) is included in the following block, linking the blocks together and maintaining a sequence forming a chain. Any data in digital format such as transactions, user identity or code can be processed in blocks on the blockchain.

Blockchain is essentially tamper-proof due to the cryptographic sealing and sequential stringing of blocks. Attackers would have to exert immense efforts in order to change information written on the blockchain, as the data would need to be manipulated on all blocks in the network and the blocks would then need to be re-validated. In addition, due to the decentralised network, a system failure of one node can be compensated by other nodes in the network. Blockchain technology can therefore offer a more secure alternative to traditional centralised network arrangements. However, its security is highly dependent on correct set-up, as discussed further.

Table 1 summarises the key technical design factors within blockchain and the implications of using different specifications.

Table 1. Key factors of blockchain designs and selected options

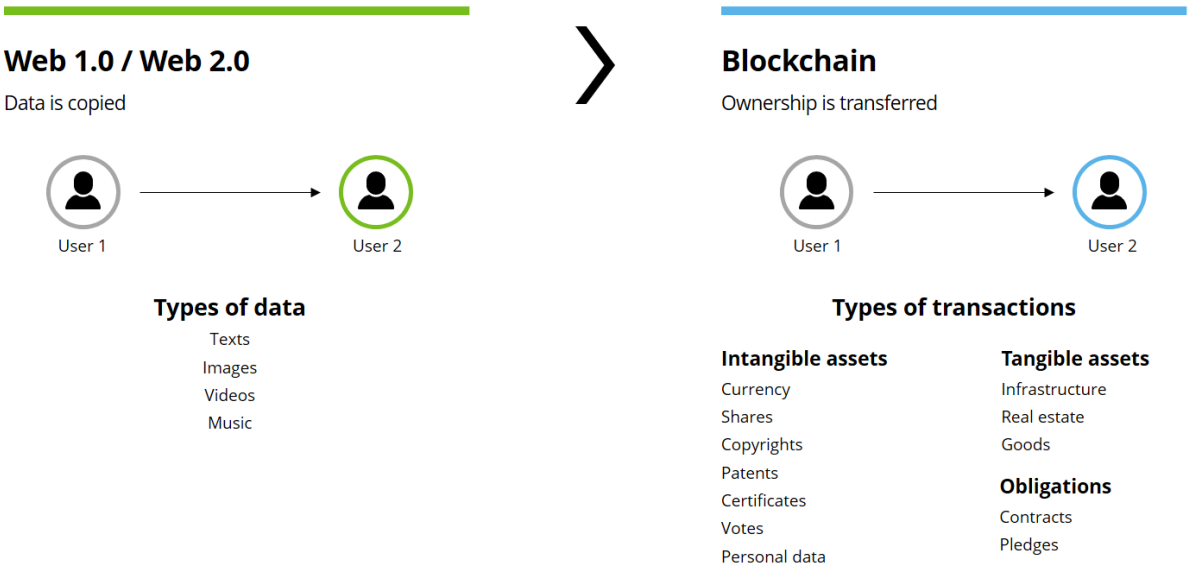
Design factor	Selected types and their functionality
Consensus mechanism	**Consensus mechanisms** are used to achieve the necessary agreement on a single data value or a single state of the network among distributed processes or multi-party systems, i.e. the validity of a block. The major ones are: - **Proof-of-work (PoW)** Consensus is generated by solving a mathematical puzzle, i.e. finding a certain hash value, that requires high computational power or work, hence the term. The first node to solve the puzzle adds the block to the chain and is rewarded with newly created coins. - **Proof-of-useful-work (PoUW)** Consensus is generated by validating the results computation deemed “useful” to society, e.g. through participating in scientific computing projects. In comparison to PoW, PoUW uses computational power to generate overall new value while also validating the next block. - **Proof-of-stake (PoS)** Miners own a stake in the network defining their share or probability to validate the next block. This leads to an incentive to follow the network rules, therefore securing a high value of the owned stake. - **Proof-of-authority (PoA)** Approved participants validate transactions and blocks in a defined order, leading to an incentive to upholding the transaction process and retaining the position that was gained. Many more examples exist including proof-of-weight (PoWeight), where the probability to validate the next block depends on a user’s ownership of a specific “weight” of a pre-defined unit other than the stake as in the case of PoS (e.g. reputation). Other concepts are highly promising, yet are in early development stages and can pose challenges in real-life implementations.

Design factor	Selected types and their functionality
Privacy	**Privacy settings** dictate who is allowed to join the network based on the need to protect privacy or trade secrets. There are two basic distinctions (hybrid forms can also be established): - **Permissioned blockchain** Participants of the blockchain network need to be approved before joining. This is either done by defined authorities or by a defined consensus mechanism. The participation as a miner depends on the defined consensus mechanism. - **Permissionless blockchain** There are no restrictions to join a permissionless blockchain network, meaning that anyone can partake in the network. The participation as a miner within the network might have constraints, which depends on the defined consensus mechanism.
Hosting	**Hosting** refers to the running and maintaining of a blockchain node on local premises or by a third party. - **On-premise** The servers hosting the miners are located within the IT-landscape of the owning entity. This guarantees full control of the node and a complete decentralisation of the different nodes participating in the network. - **Cloud** Different cloud-providers offer hosting solutions with specific blockchain services or general cloud-hosting for servers. It is important for the owner of the node to have full control, especially if multiple nodes of the same blockchain network are hosted at the same cloud provider. - **Third party** Third parties can be used to host the node within their IT. As with cloud hosting, the control of the node needs to be completely with the owning entity.
Tokenisation	**Tokenisation** refers to the use of coins or tokens on a blockchain. There are two general distinctions: - **Coin-based** Coins or tokens are the data-base of every coin-based blockchain. All transactions are related to coin movements and data is added to those coins to enable additional functionality. - **Data-based** Data-based blockchains offer storage within the blocks of a blockchain without the necessity to attach the data to tokens. All transactions include new data to be added into the chain or changes and deletions. Due to a lack of globally accepted frameworks surrounding token taxonomy, there is no common understanding of tokens from a regulatory standpoint, nor from a legal and tax perspective. Token categorisations vary and can span from utility, security, currency, commodity to hybrid forms (Token Alliance, 2018). Three main token types can be generally distinguished and will be further referenced in this report (OECD 2019): - **Payment tokens** Bearing most resemblance to fiat currencies, payment tokens are used as a means of exchange or payment for goods and service. Cryptocurrencies like Bitcoin fall under this category. - **Security tokens** Also referred to as asset and financial tokens, security tokens represent ownership of securities (or equivalent) under applicable laws. Security tokens are designed as tradeable assets held for investment purposes. - **Utility tokens**

Design factor	Selected types and their functionality
	Also referred to as consumer tokens, utility tokens represent the right to access specific goods or services. Often used as a type for pre-payment or voucher, utility tokens facilitate the access to services, but do not represent ownership of an asset.
Additional functionality	**Smart contracts** are pieces of software that are written into the blockchain and are executed by the computer network upon agreement through the consensus mechanism. **Oracles** are external data feeds that provide information from outside of the blockchain network, such as IoT sensors.

The properties of decentralised trust and immutability of created blocks enable real transfer of ownership. While it was only possible to copy data via the internet in the past, blockchain accelerates the move to an "internet of value" as shown in Figure 2. This enables intangible assets like currencies, shares, copyrights or patents to be transferred from one user to another and also tangible assets like real estate or obligations like contracts to be exchanged via the trusted ledger (Deloitte, 2017d). The transmission of tangible assets requires the creation of a digital twin, a digital representation or simulation of a physical object, which enables digital surveillance of the object (Deloitte, 2018a).

Figure 2. Moving toward the internet of value



Source: Adapted from "Will Blockchain transform the public sector? Blockchain basics for government", Deloitte (2017).

1.3. Challenges related to blockchain technology

Although blockchain promises improvements through decentralised systems, several challenges are associated with the technology.

Blockchain has been highly criticised for its high energy and resource consumption. At a closer look, this criticism is often specifically directed at the Bitcoin blockchain or, more generally, the proof-of-work consensus mechanism, which encourages specific participants

("miners") to continuously deploy resources to increase their chances of winning the race to validate the next block in the chain. Using other consensus mechanisms than PoW, as described in section 1.2, energy consumption can be significantly reduced. In addition, any comparison would need to consider the degree of energy efficiency in traditional centralised systems.

As noted, blockchain technology is deemed to be immutable and tamper-proof. However, the security of a blockchain highly relies on a suitable technical set-up, especially with regard to the degree of distribution, the choice of the consensus protocol and the cryptographic tools used (Deloitte, 2017a, Berke, 2017). Firstly, the degree of distribution of network participants, or in other words, the concentration of mining resources in one economic or decision-making entity (e.g. company) can influence security. In theory, a company or state could own, operate or influence >51% of a given network's nodes and dominate the proof-of-work consensus mechanism, thereby representing a security risk to the overall system. Secondly, the choice of consensus protocol directly affects the security of a blockchain. Depending on how new blocks are created (e.g. through mining), this process can inherently include measures which protect the system from malicious attacks. Thirdly, a protocol's underlying cryptographic elements play a decisive role in determining the security standard for a given blockchain. A number of key mechanisms are used in blockchain implementations, most notably key-pairs and hash functions (Badev and Chen, 2017, Böhme et al., 2015).

Due to this highly complex structure, it is almost impossible to manipulate previously captured transactions. The technology can therefore be regarded as a high security technology, but not without vulnerabilities. While the decentralised network is relatively safe from serious hacking attacks due to its set-up, an insecure storage of private keys might enable hackers to gain access to sensitive data. In addition, all interfaces to systems outside the blockchain environment are potentially targets for hacker attacks, if not properly secured.

It is important to note that while data securely recorded on a blockchain is immutable, it might not necessarily be correct. Incorrect data will still stay incorrect after putting it on the blockchain ("garbage in, garbage out"). The use of blockchain does not change the correctness of data. Data quality and validity checks that are written on the blockchain are key factors for consideration, as information that has been introduced to the blockchain cannot be reversed, but only corrected by adding a new block (Bauerle, 2018).

Scalability and processing speed represent additional challenges. Many blockchains are currently not projected to handle high throughput, fast processing speeds, or the large number of participants that may be required for a given application. However, continuous improvements are coming to market as the technology matures, while further theoretical developments are taking place.

With increased capabilities, blockchain could also play an important role in accelerating the adoption of other important digital technologies like the internet of things (IoT) and artificial intelligence (AI). Concerns around cyber security are currently impeding broad adoption of IoT and AI applications. The success of such applications is highly dependent on high standards of data security, clear rules about data ownership, interoperability of systems, and data reliability. The biggest cyber security priority in this realm is to make sure that there are no "weak points" in the flow of data and network architecture. Some IoT devices are vulnerable to malicious attacks based on their hardware and security properties. With regard to AI, data manipulation is a major threat, especially when thinking about use cases in autonomous driving. Blockchain technology could provide a secure infrastructure

and serve as a foundation for successful IoT and AI projects in the future, which could have promising applications for infrastructure systems (Pan and Yang, 2018).

With regard to the risks and misconceptions of blockchain and its applications, education on the technology, its design principles and their implications is required. The base protocol needs to be designed with careful consideration, given the risks and challenges. Early alignment between stakeholders and standardisation are important prerequisites for blockchain applications, yet this is challenging due to the time and effort needed in order to agree with participants on processes, data, incentives and liabilities. Many regulatory topics in this respect are still in discussion. The need for standardisation and the current regulatory environment are further discussed in 5.2.

Box 2. Blockchain and energy consumption

Blockchain, or more specifically its first application Bitcoin, is often times linked with high-energy consumption, especially in mainstream media. The immense power consumption is mainly the result of the proof-of-work (PoW) consensus mechanism. This consensus algorithm requires high computational power to solve a mathematical puzzle in order to validate transactions, while many computers compete with each other in order to solve the puzzle and extend the blockchain with new blocks. The decentralised approach to validating transactions and amending new blocks to the blockchain allows for resilience and immutability, yet, coming at the cost of high resource intensity. Another result of the PoW mechanism is that tampering the transaction history recorded on the blockchain requires a significant resource investment, reducing the financial viability of such attacks.

Since the early experiments with blockchain technology, many more platforms that adopted different consensus algorithms (e.g. proof-of-stake) have emerged. Aiming at widespread adoption in enterprise settings, less resource-intensive mechanisms have been developed and implemented. Given that within business networks and enterprises, there is already an initial degree of trust between the participants, a high degree of decentralisation of trust is often traded for less resource intensive consensus mechanisms.

Blockchains in the business context, especially within consortia, are predominantly set up as private blockchains using algorithms like proof-of-authority (PoA). If designed accordingly, private blockchains do not consume more energy than traditional database solutions.

Other applications of DLT like Holochain, Tangle, and Hashgraph have emerged using differing approaches to build decentralised networks. The market for cryptographic technologies is still relatively young and is continually evolving to address known challenges – new algorithms, consensus mechanisms, and methods for sharing data or validating transactions are likely to emerge as DLT matures.

See section 1.2 for technical details on consensus mechanisms.

2. Blockchain's role in enabling sustainable infrastructure investment

It is estimated that annual investment of USD 6.9 trillion through the year 2030 is needed in order to maintain growth trajectories and to achieve with increased confidence climate change objectives and the Sustainable Development Goals (SDGs) (OECD, 2017). Significant challenges also arise regarding the lack of data transparency in current governing systems and the need to involve private and public institutions, as well as end consumers, in the infrastructure value chain. As for achieving the Paris Climate objectives, Figure 3 shows the key challenges, which could be effectively addressed by leveraging blockchain technology:

Figure 3. Key challenges of the Paris Climate objectives that could be addressed by blockchain technology

- **Financing infrastructure** – New sources of financing, including a well-aligned investment environment, represent key requirements going forward in the low-carbon transition. Transparent and clear processes can serve to gain the trust of investors. Blockchain technology provides a digital layer that helps to tackle these core requirements. New sources of capital can be leveraged by developing efficient blockchain-based investment platforms to finance projects globally. By employing an appropriate blockchain set-up, overall transaction costs could be reduced and the participation of small-scale investors such as small and medium enterprises (SMEs) and individual consumers could be made feasible. Through end-to-end tracking and auditable data trails, investors may transparently track their investments. For successful implementation, an international legal framework would need to be established, which allows for simple investment transactions for the full spectrum of investors.
- **Visibility and alignment** – In the current system, it is difficult to track where climate finance is allocated and to measure its impact. The problem is even more severe as the top recipient countries for climate finance are often also countries with high levels of corruption (Transparency International, 2014). Most countries lack comprehensive and consistent information systems that can show investment pipelines and existing infrastructure, thus impeding decisions on future investments. Global visibility of investments through consistent, reliable and accessible data (including ESG reporting, and climate-related financial disclosures) will be needed on a global scale in order to

effectively steer climate action and reduce search costs for investors. For governments, a transparent information system showing infrastructure pipelines and current operational assets will be a key tool to coordinate and align climate action with other governments or the private sector. By provisioning the right digital infrastructure based on blockchain technology, deeply entrenched, but flexible monitoring, reporting and communication services can be developed in the future. The time to generate reports based on this data can be reduced significantly. As an example, the Intergovernmental Panel on Climate Change (IPCC) could be supported in the preparation of their regular Assessment Report (IPCC, 2018).

- **Awareness and access** – As private and public institutions as well as the global population are important levers in the transition to a sustainable future, it will be essential to build global awareness around environmental issues and increasing consumers' willingness and ability to contribute to climate-friendly action (Nielsen, 2015). Blockchain can act as the transaction-enabling infrastructure of new market models, in which users are incentivised to invest sustainably. Using token- or cryptocurrency-based models and gamification approaches, efficient markets for carbon offsetting activities can be built and scaled. This approach requires customer-centric market models and applications, which are easy to understand and use. Education and providing access to blockchain-based applications will be key for successful implementation.

Many critics argue that the current plans, as set by countries in order to achieve the targets of the Paris Climate Agreement (through nationally determined commitments (NDCs) and private company targets) are not sufficient to meet the ambitious investment goals set by governments. Hence, to support current and future efforts, a strengthened collaboration and technology framework will be essential. The subsequent chapter presents the key requirements to support action aimed at tackling the challenges stated above. Based on these technical requirements, blockchain technology's key value-add is outlined. Section 2.2 summarises today's representative use cases and application areas of blockchain, based on the challenges in the low-carbon transition.

2.1. The need for more efficient digital infrastructure enablers

To address the previously mentioned requirements to ensure that infrastructure is aligned with country and regional investment strategies, organisational and technology-based approaches have to be transformed. As observed in other areas in the public and private sectors, managing climate-related action will require the adoption of innovative digital enablers. Interoperable and well-entrenched "end-to-end" digital data services will be required to increase efficiency. Relevant data, particularly on ESG criteria, needs to be accessible through standardised interfaces, as opposed to being collected in a redundant and uncoordinated fashion through a multitude of databases. While a variety of databases and reporting platforms already exist, they are mostly fragmented. A decentralised network of systems could represent an option to reduce friction in data and transaction flows, while improving on data standards for infrastructure performance reporting (Mattila and Seppala, 2015).

Traditionally, a trusted centralised entity would be mandated to set up such a global "single source of truth". While centralised entities have many advantages, complex multi-party relationships that require a high degree of transparency and immutable data trails are arguably better served by decentralised blockchain ledgers. The advantages provided by blockchain technology are summarised in Table 2.

Table 2. Blockchain's benefits in addressing requirements of digital enablers and systems

Requirements	Solutions implementable on a blockchain
Transparency	The fragmented landscape of process standards and systems leads to many isolated entities holding valuable information for making choices on infrastructure investment, financial forecasting, mitigation and adaptive action. Decentralised ledgers and transaction networks can be a catalyst for standardisation and transparent monitoring, reporting and steering of data collection. For instance, infrastructure financing commitments made by governments, infrastructure contracts and pipelines, and complex public aid schemes can all be registered and analysed on shared ledgers. Reliable analytics services based on the trusted and accessible data trails add a unique opportunity to supporting the alignment of decision-making and investment flows. Accordingly, efficiency gains in supporting functions and administrative processes can be realised on treaty-level, as well as for local government- and company-levels. By deploying "track & trace" functionalities, blockchain can uniquely identify and keep track of movements of physical or virtual goods. The tracing of tangible objects is often achieved by using hardware (e.g. near-field communication "NFC" chips), and intangible objects could be represented by certificates. Challenges arise in the tagging of substances (e.g. in the chemical industry), where tracking is often achieved by tagging the tangible containers.
Data auditability and privacy	Due to the current isolation and fragmented governance, the integrity of data cannot be comprehensively assured. In addition, ensuring data privacy poses a key challenge. Given that redundant and mismatched data is collected within many organisations, the inter-company exchange of data is uncontrolled and opaque to their owners. Based on the single book of accounts, blockchain provides the means to maintain, monitor and analyse data without undermining data privacy and sovereignty. Depending on the blockchain protocol's design, transactions can be made visible only to the related parties, and in addition, parties can interact pseudonymously on the network. Pseudonymity assures an integral data trail and book of records, without revealing a transacting party's identity to the wider network or public.
Process efficiency and automation	The effectiveness of today's network of systems that is used to plan and finance sustainable infrastructure is limited, given numerous non-standardised interfaces and security issues. Cross-border transactions, for example, suffer from a high degree of manual intervention and non-transparent data trails. Building on a blockchain layer, smart contracts can further improve transaction efficiency by automating standardised business processes and payments. Processes like digital entity or asset registrations could be handled much faster for all involved stakeholders, and additionally provide full transparency and traceability of all registrations.

Leveraging blockchain as the digital infrastructure enabler, a foundational blockchain layer could be established, on top of which other blockchains, leveraging also other applications like IoT or AI could be deployed for various purposes. A detailed description and discussion is provided in section 3.4.

As outlined in Table 2, visibility of the infrastructure pipeline is of essence. However, assigning a unique identification tag, according to a standardised convention, is not enough. Immutable IDs of assets and projects have to be seamlessly integrated with related IT systems and monitoring services. By adopting a decentralised registry based on blockchain, a new renewable power plant (as an example) with its key specifications can be registered globally. Rather than locating this process with various national and sub-national entities, an effective cross-border system could be provided by participating governments. Government institutions, DFIs, NGOs, companies, users, and any other entities could be linked to such a platform. In addition, entities that submit information to such platforms (e.g. utility providers, transport authorities, livestock farms), remain the sole owners and

are responsible for the data points in the shared ledger. The transparent, but pseudonymous, tracking of data flows and access management allows the data owners to manage their transactions and interfaces efficiently, without compromising data privacy protection.

Another example is the monitoring of compliance. Blockchains enable the tracking of compliance with technology standards. For instance, infrastructure owners or operators may be legally required to report status information and changes to their infrastructure. Air quality stations in urban locations could be standardised in terms of data quality, identification and software. By implementing an automated monitoring service (such as through sensors that automatically record and transmit quality checks), data from non-compliant air quality stations, and their operator can be flagged and reported to responsible authorities. As data is recorded on the blockchain, automated and even smart reporting and monitoring services can be enabled, bringing together a patchwork of data sources such as satellite imagery, remote IoT sensors, engineering reports, and regulatory reports. Authorised organisations may track the compliance of new infrastructure projects and their financing by setting a compliance and anti-corruption reporting standard that is incorporated on the blockchain network.

Looking beyond the technology's potential to tackle the aforementioned issues, it is important to note the implied depth of a blockchain's integration with the current systems, processes and infrastructures. Compared with other technologies like cloud storage and computing, blockchain technology provides a significantly deeper interaction with processes. Successful blockchain applications require an ecosystem of collaborating parties, who exchange and validate information. With regard to infrastructure, the orchestration of partners and suppliers could take a new dimension by IoT devices, e.g. when using sensors that provide real-time access for stakeholders or act as oracles, which provide information to smart contracts. In this regard, data and process standardisation is a crucial prerequisite for successful blockchain implementations, as described in section 1.3. This applies to applications (e.g. streamlining data collection and availability with user journeys) as well as the organisational set-up (e.g. agreement between application owners and node operators) (Glaser, 2017).

Adopting blockchain networks at the treaty-level, e.g. United Nations Framework Convention on Climate Change (UNFCCC), and government-level, will require standardised protocols and interfaces to leverage process efficiencies and transparent reporting. Through this, financial flows could be made visible and can thus be better aligned, as stipulated in Article 2.1.c, and Article 6 of the Paris Agreement (UNFCCC, 2015). For example, under Article 6 of the Agreement, parties are authorised to negotiate the transfer of some portion of a signatory nation's NDCs to another signatory nation (deemed to be Internationally Transferred Mitigation Outcomes, ITMOs) (CLI, 2018a). In this respect, blockchain can encourage agreement on methodologies to track investment flows, and to ensure robust carbon accounting standards.

Given the highly complex relationships and high numbers of actors in the realm of financing and monitoring low-carbon infrastructure, close collaboration and mutual understanding of the technology will be of essence. Today, this advanced degree of corporate collaboration is already in full swing. Within several industries alliances and consortia have been formed, consisting of leading private corporations, public and private research institutions, and technology start-ups. Building viable approaches to adopting blockchain technology and accelerating its maturity, these projects have already yielded new business and market models.

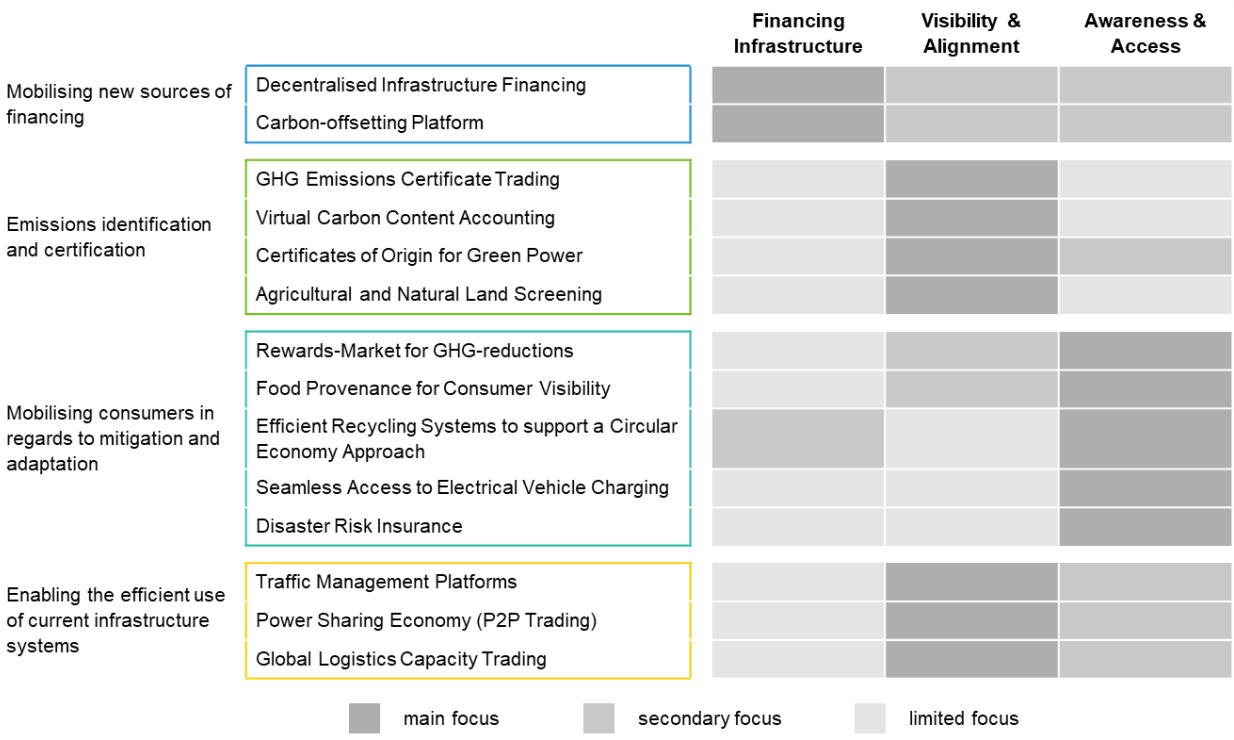
2.2. Blockchain as an enabler of mitigation and adaptation-related activities

The role of blockchain in the context of sustainable infrastructure is considered to be far beyond enabling efficient data collection, monitoring, reporting and steering services. The technology can potentially also address the key challenges and opportunities in supporting mitigation and adaptation-related activities, especially in the energy, transport and agriculture industries. Mitigation refers to the reduction of future GHG emissions, which can for example be achieved by assuring that newly planned and built infrastructure is compliant with climate objectives. Adaptation relates to action that helps to cope with inevitable effects of climate change, for example insurances for climate-related damages.

Today, a number of blockchain-based services relevant to both mitigation and adaptation have advanced to prototyping and piloting phases. Start-ups and corporate projects are continuing to advance the technology and validate market models. Consortia partnerships and development activities show great potential to scale blockchain networks among immediate stakeholders and beneficiaries.

In the following, a non-exhaustive selection of relevant use cases is presented, which are pursued in the realms of energy, mobility and agriculture. In Figure 4, the cases are clustered in categories of action that all account to addressing the three main challenges described in section 2. , leveraging the advantages of blockchain technology as outlined in 2.1.

Figure 4. Relevant use cases in regards to mitigation and adaptation



2.2.1. Mobilising new sources of financing

Leveraging new sources of financing for infrastructure will be one of the key determinants of reaching investment goals. One of blockchain technology's most promising applications is the idea of a decentralised financing platform for infrastructure. Chapter 3.1 of this report presents an original case study on this subject. Similar to the investment platform, pollution-offsetting programmes can be supported by a decentralised ledger. Providing unique identification, allocation and tracking services, offsetting commitments can be integrated in corporate sustainability programmes.

Examples of relevant use cases

Decentralised infrastructure financing - Similar to today's crowd-investment platforms, assets such as renewable power plants, bike paths, efficient agricultural facilities (e.g. aquaponics and hydroponics), and many more, can be financed by direct participation of small to mid-size businesses, institutional investors, public sponsors and private individuals. Given blockchain technology's benefit of process efficiency, transparency and fast settlement, even microfinancing can become feasible to outweigh the operational transaction costs and allow for a wider spectrum of investors to participate.

Carbon-offsetting platform - Companies and public institutions choosing to offset their footprint may easily commit a desired amount to a decentralised platform of infrastructure projects. By reducing the transaction costs and strengthening the auditability of their commitment, organisations will have the chance to commit more resources than before. A globally implemented blockchain-based solution, which operates as a not-for-profit, may minimise transaction costs and eliminate the risk of monopolistic behaviour observed in traditional digital marketplaces. In addition, commitments can also be efficiently disclosed to ongoing regulatory measures such as quotas and certificate trading schemes.

2.2.2. Emissions identification and certification

Driving climate change-aware behaviour intrinsically or extrinsically through financial incentives requires a comprehensive, reliable and secure digital backbone that provides the necessary information for such decision making. Whereby today some approaches exist, their restricted interoperability leads to a fragmented landscape of systems, thus hindering widespread adoption among customers and businesses. Blockchain technology can enhance the effectiveness of such solutions, by providing the overarching standard to unique identification and recording transactions of e.g. carbon certificates, their trading, and even the origin of GHG emissions. This transparent and immutable record makes it easier to monitor and incentivise, or impose penalties on, certain industrial practices. Building on existing carbon market models, more efficient and highly integrated trading platforms could be established. A detailed consideration of how these benefits can be leveraged is presented in section 3.2.

Examples of relevant use cases

GHG emissions certificate trading - By using blockchain technology, a highly automated and self-governing decentralised ledger that incepts, holds, tracks, and destroys unique certificates for real-world emissions could be globally implemented. Depicting a new foundational infrastructure layer for the currently implemented carbon certificate systems (e.g. EU ETS), a far more flexible and deeply entrenched certification and trading service can be established across all markets. Quota rules and certificate circulation can be controlled by the rules defined in smart contracts, which enforce certificate-related transactions in an automated fashion. On the other hand, climate-mitigating investments (e.g. forests and wetlands) could be sources of carbon credits, which could be monetised by creating, tracking and trading newly generated credits using blockchain technology.

Virtual carbon content accounting - While emissions trading systems (ETS) account for a company's emissions and monitor the adequate compensation through trading of emissions certificates within a specific geographical market, they

do not account for emissions that are generated by these same companies outside the trading system's jurisdiction (i.e., "scope three" emissions under the GHG Protocol standard) (GHG Protocol, 2018). In order to accurately assign all emissions that are caused globally by a single company, the carbon content of products and services needs to be identified and tracked across the value chain (lifecycle approach). The carbon content of products, unprocessed products or intermediate inputs can be registered on a blockchain-based system to track the virtual content of imported or exported products, allowing regulators to comprehensively enforce action against climate change.

Certificates of origin for green power - By uniquely identifying and tracking power from renewable sources throughout the value chain (generation, distribution, storage, consumption), a variety of use cases can be enabled. For instance, emissions caused by the generation of power used by electric vehicles can be uniquely identified and allocated to each charging process. An open-source decentralised application (dApp) being developed by the Energy Web Foundation has already been tested on several sites. The application offers more granular data (about power ownership, location, time, and avoided marginal CO_2 emissions for each kWh) while enabling direct, automated certificate of origin trading between renewable energy generators and buyers of any size (EWF, 2018). This allows consumers to have an enhanced ability to identify and procure from renewable energy assets with greater avoided marginal emissions potential. Blockchain-based solutions modernise the technology tools available for renewable energy tracking, trading, and reporting systems while also disintermediating the process and reducing transaction and administrative costs in certificate of origin markets.

Agricultural and natural land screening - By combining remote sensing, image processing and blockchain technology, a verifiable screening of forests and agricultural land can be established. The natural carbon sinks can be accounted for in near real-time and payments related to their growth, or shrinking can be settled automatically and securely on a blockchain-based platform. For example, the platform can allow screening for the achievement of company or country level mitigation commitments (CLI, 2018b).

As this platform will require necessary image sensing and processing technology, significant investments for a comprehensive coverage are necessary. Yet, a crowd-sourced data platform, connected to suitable (nano) satellites may provide the data for a fraction of today's prices and maintain data integrity. Initiatives have already started to explore options of using remote sensing to provide earth observation data at low cost and high security (Stocker, 2017).

2.2.3. Mobilising consumers in regards to mitigation and adaptation

Apart from industrial behaviour contributing to GHG emissions, end consumers are also an important lever for building inclusive infrastructure systems. In order to mobilise consumers, it is important to raise awareness, reward sustainable behaviour, provide suitable infrastructure to reduce consumer burden and accelerate adoption levels of individuals.

In this regard, blockchain may provide the IT backbone to transparent information on emissions and consumer choices. Genuine and auditable information on the blockchain can help to increase awareness and design incentives for behaviour that meets certain standards.

To effectively participate in mitigation and adaptation, consumers need to be provided with a suitable infrastructure, which reduces their own individual burden of making sustainable choices. To name one example, the electrification of vehicles is one of today's biggest challenges in the transport and mobility sectors because of the extensive consumer burden caused by lack of charging infrastructure, costly battery systems and user inconveniences in using battery electric vehicles. Consumers and institutions need to be given the right incentives as well as opportunities in order to change behaviours in the long-run.

Examples of relevant use cases

Rewards-market for GHG-reductions - A blockchain-based cryptocurrency and marketplace could be established, which rewards consumers and organisations that take decisions with a positive environmental impact. For instance, a start-up from the U.K. introduced a platform rewarding human activity by foot. By walking, a cryptocurrency is transferred to the user, who can use the credit on a decentralised exchange of merchants offering their services ranging from graphic designers, local food retailers, to NGOs receiving donations (Sweatco.in, 2018). This idea can be transferred to decentralised platforms rewarding users with cryptocurrency. As the platform grows in users and merchants, the value of the cryptocurrency increases and network effects drive the platform's impact.

Food provenance for consumer visibility - A blockchain-based solution for the tracking of food supply chains could provide transparency to consumers about the origin of production. By introducing a label on products indicating the source and including a link to an open database, consumers see whether their food has been sourced in a sustainable way. A prominent example is the track and trace case for tuna to combat illegal fishing. Using devices for tracing (e.g. RFID tags, QR codes, NFC devices, or cameras), information about the fish can be collected at almost any point throughout the supply chain (Visser and Hanich, 2018). As the data is recorded on a transparent and immutable registry, each fish can be tracked back to its origin by respective regulators, NGOs, and consumers. The technical implementation of this use case can be applied to other natural capital in agriculture, livestock, and forestry.

Efficient recycling systems to support a circular economy approach - Participation in recycling programmes, although greatly contributing to a sustainable future, currently has few incentives. Through the use of blockchain technology, suitable reward systems can be established to provide transparency and to ensure secure transactions. As an example, a start-up company built an efficient plastic recycling system for developing countries. Individuals can collect and bring plastic refuse to established recycling centres, which in return repay collectors in the form of digital tokens. The received tokens can be used to buy goods like food, water or phone credit. As many of the targeted users are unbanked, the alternatives are cash or mobile payments. Cash payments are especially vulnerable to corruption and crime, making blockchain-based transactions an alternative (Frankson, 2017). In developed countries, blockchain could be used similarly in order to set incentives for responsible consumption, giving different countries a means to help transition upwards in the waste hierarchy from disposal, to recycling and waste prevention, depending on the country's specific infrastructure and consumer prerequisites and needs (Cooper, 2018).

Seamless access to electric vehicle charging - So far, the expected and required rollout of electric vehicles has not yet occurred globally. In addition to high battery costs, there is room for improvement in the required charging infrastructure. Among other factors, the interoperability between charging networks is restricted and leads to an unattractive customer experience. To reduce the consumer burden of adopting e-mobility, a technology venture named Share & Charge has proposed a blockchain-based charging experience. The platform promises to provide open access to any charge pole, including a P2P sharing model. The utilisation of charging infrastructure can be increased to cater to more consumers, reduce costs and due to its technical flexibility, allow integration with adjacent services such as smart grids.

Disaster risk insurance - Some unavoidable effects of climate change can lead to the loss and damage of property, with poor and vulnerable people disproportionately affected. Enhanced disaster risk insurances could provide rapid emergency assistance and financial help to reduce negative impacts from drought, floods or cyclones (Insuresilience, 2018). A lack of full transparency on insurance contract designs, payment terms and the speed of claims pay-outs account for today's most pressing obstacles to effective disaster insurance. Adopting decentralised platforms and automation by smart contracts integrated with oracles (e.g. weather and disaster information), payments based on parametric insurance could be triggered automatically and instantly. By maintaining the complex insurance and re-insurance contracts on shared ledgers, an inclusive data foundation and transaction engine can be created to support disaster recovery efforts. This might not only increase the efficiency by cutting out administrative overhead, but also provide immediate help in situations of need. Such shared ledgers, with open interfaces to related data providers, would allow for a more efficient calculation of underlying volatility, thus leading to potentially reduced insurance premiums. Insurance for disasters may become gradually less cost-intensive given the transparency and access to better data.

2.2.4. Enabling the efficient use of current infrastructure systems

By creating an efficient transaction platform based on a suitable market model, the capacity of today's infrastructure systems can be better utilised. Based on a snapshot of today's

infrastructure utilisation rates, all key industries, ranging from power grids, private and public transport assets, or agricultural land, will benefit from such action. Especially in the fields of urban mobility services and power grids, many emerging start-ups and other players have proposed suitable use cases. Blockchain technology supports this development as it enables micro-interactions between a large group of participants in an efficient and secure way. Platforms rewarding, penalising or automating specific behaviours could be developed based on blockchain technology and, because of the required standardisation, would be highly interoperable.

Examples of relevant use cases

Traffic management platforms - By securely and selectively sharing the data from mobility assets in a relevant ecosystem of stakeholders, such as auto OEMs, municipal bodies, and map and routing service providers, specialised analytics software can evaluate the data and dynamically set incentives to prefer or avoid certain streets at certain times. In conjunction with today's discussions on restricting combustion engine vehicles in urban city centres, or implementing special tolls, the integration of sensor data (e.g. pollution measurement stations, virtual toll area screening, etc.) and collection of vehicle data on a blockchain network can significantly increase the effectiveness of such mechanisms. Each municipality could design an appropriate traffic control system and implement it as a real-time application on the blockchain layer. Monetary incentives (or fines) can be transferred directly between wallets held by the (shared) mobility assets, its owners or users.

Power sharing economy (P2P trading) - So-called "prosumers", may use their "home-made" energy (e.g. through solar, wind turbines or combined heat and power plants), while also selling the excess energy on a highly automated decentralised platform. Selling the surplus power increases efficiency and resilience of the power plant portfolio, and provides an incentive for the private sector to invest in renewable power plants. Local grid operators and integrated utilities may benefit from more efficient grid operation and decreasing demand for traditional generation assets and power transport infrastructure. However, the shift to a decentralised grid also represents tremendous disruption to traditional power and utility business models (as well as to power grids themselves which were designed to distribute power from generation to consumer, not from consumer to consumer) and requires increased awareness and knowledge on the part of consumers (Steinberger et al., 2018).

Global logistics capacity trading - The global logistics industry faces many challenges. One of which is managing capacity and utilisation rates in a cost efficient manner. Today many companies are not utilising holding capacities to their fullest extent, as isolated digital systems and limited visibility of capacities result in varying levels of occupancy from low utilisation rates to full capacity. By developing an open registry and transaction backbone for logistics capacities (e.g. containers), available holding capacity can be offered to a broader spectrum of customers while fewer resources would be needed to transport the same amount of goods. Compared to a regular database approach, blockchain provides transparency and security through distribution of data and validation by independent parties. The technology also enables companies to control their data and decide which information is shared with which partner and competitor (e.g. pricing terms). Currently, shipping companies and ports are actively pursuing blockchain solutions for their logistics data in order to improve visibility and reduce fraud (Miller, 2018).

As an outlook for the mid-term future, digital platforms serving different purposes can be interlinked. The crypto tokens (coins) in circulation on each platform can be used as a currency to engage other market platforms as well. For example, in the case of a P2P power-trading platform and a separate reward system for end-consumer behaviour, a user that receives tokens for riding a bike to work instead of using a car could use the awarded credit to buy renewable power produced by a neighbour in the local community.

In summary, there are many ongoing efforts and ideas on implementing blockchain technology in order to support a sustainable infrastructure system. Their level of complexity and the resources needed for implementation vary significantly from case to case. Four use cases are presented in section 3. in the form of case studies with potentially high and valuable impact on the governments and institutions seeking to expand their infrastructure services. Derived from the case studies, implications for policy makers in regards to blockchain use cases are discussed in section 5. .

3. Case studies: Blockchain for sustainable infrastructure

In the following, a series of select case studies are introduced presenting the application of blockchain technology in supporting the low-carbon transition. Cases such as blockchain-based financing platforms, carbon emissions markets, effective contract management and a concept for global action and infrastructure monitoring are expected to address some of the key challenges facing sustainable infrastructure investment, and can have a high impact on the fulfilment of investment objectives. The relevant stakeholders on intergovernmental, supranational, national, business and private consumer levels prospectively hold different roles and responsibilities in initiating, developing, and provisioning such blockchain systems.

Each case study is structured in three sections. Initially, the overall concept and envisioned application with its main functionalities are outlined. Therein, a succinct summary of the relevance to sustainable infrastructure development and the underlying key challenges and benefits are introduced. Secondly, the case studies contain descriptions of possible adoption scenarios and a viable way of implementing and using the technology. Each case study concludes with a proposition for a potential high-level roadmap illustrating the initiation, provisioning and operation of the described application. Section 4 ties the case studies together by providing a roadmap for the implementation of ideas and creating pilot programmes.

3.1. Developing sustainable infrastructure via blockchain-enabled financing platforms

Supporting the development of sustainable infrastructure by efficiently opening up new channels of financing is an essential step towards achieving investment objectives. Financing platforms that collect and distribute investment for infrastructure projects, such as renewable power plants, transport infrastructure (e.g. bike roads, community car sharing), sustainable food sourcing and supply chains, as well as natural capital, pose a promising model. However, the associated operational inefficiencies and high transaction costs currently offset the benefits. For institutional investors, occasional investments in different projects that are not embedded in larger contracts or agreements are less attractive due to complex contracting and lengthy internal coordination processes. On the other hand, project initiators need long-term power purchase agreements with creditworthy off-takers before they can obtain financing, which is rarely the case with smaller scale projects, especially in developing countries (Deloitte, 2018b). It is also currently not feasible to raise funding from micro investors through crowdfunding, as the handling of contracts and payments for each individual would exceed the benefit gained from the marginal funding.

Blockchain technology could be used to provide an efficient financing platform mechanism, which allows physical and digital goods to be tokenised, exchanged and audited. Today, the preferred method to raise capital for projects, mainly by blockchain technology firms, builds on the aforementioned crowdfunding model. Dubbed “initial coin offerings” (ICOs), companies and entrepreneurs raise equity capital by virtue of issuing

native tokens in return for cryptocurrencies, or more rarely also for fiat currencies (Adhami et al., 2017, Conley, 2017).

ICOs have experienced an extreme growth phase and have outperformed traditional financing channels in terms of absolute investments in the year 2017. Since then, in the course of 2018, the ICO hype has significantly decreased due to rampant speculation and increasing instances of fraud. Nevertheless, the underlying concept of tokenisation (as described in section 1.2) still holds much potential in representing and trading value on a blockchain and can still be leveraged in many blockchain applications. Using the same investment and token trading vehicle, capital can be raised for the financing of infrastructure development in the form of debt or equity issuance.

The Global Infrastructure Hub is currently working on a concept to leverage blockchain technology in debt financing of infrastructure. Within "smart infrabonds", debt service payments would be issued to bondholders automatically via smart contracts, enabling lower transaction costs and potentially denominations of smaller amounts (Moseley, 2018). The World Bank's blockchain bond, which relies on fiat rather than crypto as underlying currency, is another example (Duran and John, 2018). Since classifications of tokens are not internationally standardised and there are many legal viewpoints (see section 1.2), clear regulation and standards are needed to provide the necessary consumer protection in case of broad adoption of token-based blockchain applications.

Through blockchain-based financing, the full spectrum of investors from large sophisticated institutions to microfinancing channels get the opportunity to invest in projects by purchasing tokens either with crypto or fiat currency. By using such openly accessible, highly automated investment vehicles, additional sources of financing in the wider public and private sectors can be leveraged without carrying the burden of transaction costs and management fees. Moreover, the digital representation of assets on decentralised marketplaces (tokens) enables investors to trade ownership or proceeds (e.g. electric power) efficiently.

While it is evident that blockchain technology offers a high disruptive potential for equity shares in terms of efficiency and cost reduction, it is difficult to quantify the savings in time and resources. Existing studies suggest a cost reduction of more than 10 percentage points of tokenisation in comparison to conventional IPOs (Uzsoki, 2019). However, this is highly case dependent and it is difficult to extrapolate implications from general market numbers. While cost structures for an IPO and ICO may not be directly comparable due to differences in regulation, real savings can be realised in the post-IPO/ICO stage. Thinking of tasks such as dividend payments or shareholder voting requiring many intermediaries such as accountants, lawyers, and bankers, switching from paper-based to digital ownership with the issuance of equity tokens permits full code-driven automation without intermediaries and at reduced cost of governance.

Depending on the token set-up, tokens can represent real equity stakes (e.g. of the to-be-built infrastructure, or an operational asset that is refinanced through the platform), or used to run applications on the network (so-called consumption or utility tokens). The investor therefore either receives return on investment as consequence of the value gain of equity or through dividends, or receives future services that are offered by the investment project (renewable power, access to shared bikes, etc.). This core concept is described in greater detail in section 3.1.1.

Lithuanian-based WePower is developing a blockchain-based green energy trading platform, which makes it possible for green energy developers to raise funding by selling

future energy production in the form of tokens. During the presale, the company raised USD 30 million comprised of USD 11 million from the public ICO and USD 19 million from traditional investment funds. This real-life example illustrates the potential and the high level of interest concerning blockchain-based investment platforms. Another example is the Australian technology company Power Ledger, which developed in 2018 marketplaces for transacting energy and ownership of renewable power plants using blockchain technology. One of these token-based marketplaces, known as an "asset generation event", provides direct access for registering and trading ownership of power plants. The project's aim is to facilitate fractional ownership of solar farms and community battery systems. Power Ledger is rolling out its first asset, rooftop solar based in Australia, in the next few months. It should be noted that many blockchain businesses are risky ventures, often employing new ideas in untested markets, or using untested approaches where demand and adoption may be difficult to forecast, similar to venture capital investing.

3.1.1. Potential market and technology design

Incorporating the decentralised financing model initially requires the development of an investment platform. A multi-sided platform, allowing access to investors, infrastructure project sponsors, insurances, contractors, and additional relevant stakeholders, would help to coordinate interactions among actors. It could be established by public institutions and governing bodies as well as private institutions, who by taking the responsibility of development and provisioning, have the authority to register project initiators and check published projects for validity and regulatory aspects. After registration and successful checks, infrastructure project initiators could use this platform in order to publish information on planned projects, including detailed project plans and pricing information. Based on this input, investors could make informed decisions on which projects to support.

Figure 5 shows an exemplary user journey for an investor. Depending on the focus country and its existing infrastructure in telecommunication as well as prevalent user preferences, there are a multitude of possibilities for designing the user platform and shaping user interactions. Investors could for example access the platform via mobile device applications, websites or could engage in investments via text messages. The platform gives a market overview of all projects that are eligible for investment. Based on the information given, the investor chooses a project to invest in, transfers the desired investment amount using specific wallets or payment interfaces to the project initiator, and in turn receives tokens.

While investing in projects through the blockchain-based platform, the received tokens can represent different rewards or services, or financial instruments, depending on their set-up. Security tokens, could allocate fractions of equity ownership in infrastructure projects, such as individual solar panels, partial ownership of wind power stations or bike roads. In the case of renewable power plants, the produced energy is provided for local consumers for a usage fee, which is in return proportionally distributed among the investors as return on investment. Utility tokens could be used for future services that will be provided by the project initiator, for example receiving verified renewable energy from a wind power station. Essentially, a cryptocurrency value based on the underlying commodity (e.g. power) is created and exchanged among the investors and consumers. This concept also enables investors to sell their tokens on the market at any given time.

Figure 5. Investment platform user journey

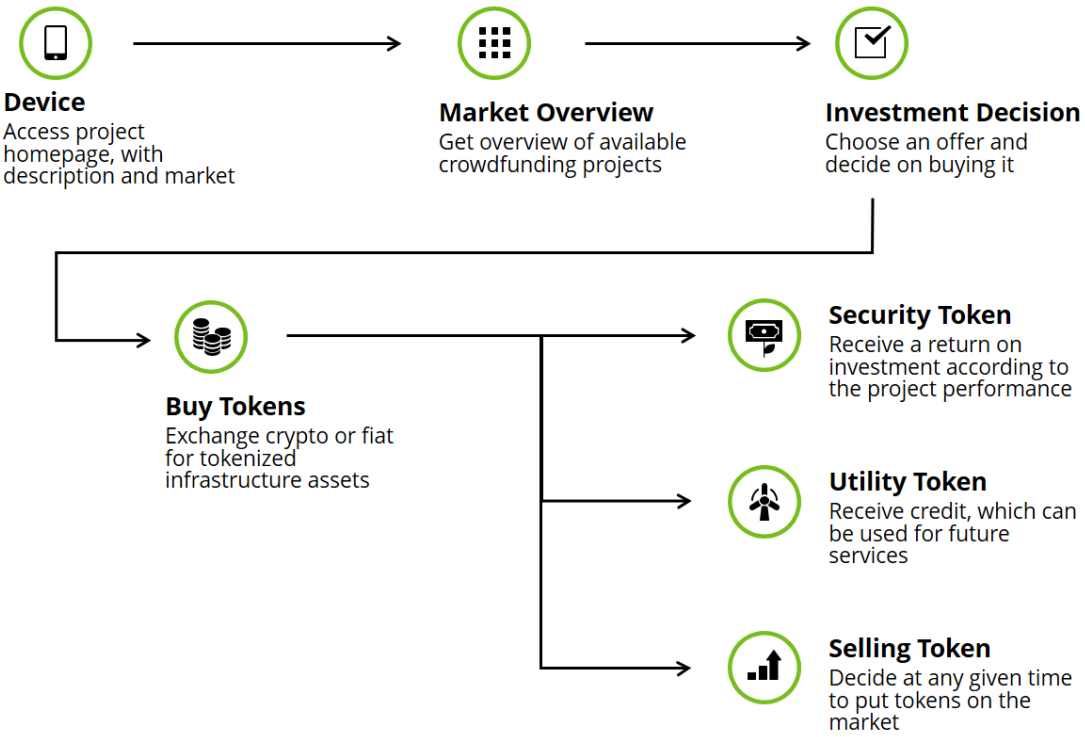


Table 3 introduces an initial set-up for a blockchain-based crowdfunding platform and represents one of an array of possible scenarios.

Table 3. Possible technical set-up of blockchain-based crowdfunding platform

Design factor	Selected types and their functionality
Consensus mechanism	**Proof-of-authority (PoA)** Approved participants will initially create the network and run the consensus mechanism as PoA. Additionally, new validators can be on-boarded over time. Project initiators and investors alike can validate transactions to reach distributed consensus, once the network grows.
Privacy	**Permissioned or permissionless blockchain** The blockchain underlying the platform should initially be set up as a private blockchain. This ensures a controlled environment for the pilot stage and the first crowdfunding transactions, which prove the feasibility of the overall concept. Participants of the blockchain network need to be approved before joining the network using the PoA consensus mechanism.

	As more project initiators and investors join the platform, it can as an option gradually move to an open source, permissionless blockchain to widen the reach and further decentralise the network.
Hosting	**Multiple options** Hosting is not limited to one option; on-premise, cloud and third party hosting are possible. The preferred method for the core-network is on-premise at each participant's site, creating the most trust in the decentralisation of the network. Once more participants join, the new parties can decide to delegate their hosting to a cloud solution or another third party. The governance of the network is spread over the network itself by approving new participants and by the option to delegate hosting using the PoA mechanism.
Tokenisation	**Coin-based** Blockchain underpins the crowdfunding platform, which can thus be token-based. A token can represent any kind of asset or right to a future good or service and can be traded by the participants. This creates a micro-economy, giving different tokens different purposes and values and therefore generating a market within that platform. The set-up can either be as: - **Security token** Partial ownership of an infrastructure project or asset is represented through a security token and can be exchanged between market participants - **Utility token** Access to goods and services provided by the infrastructure project. A utility token can be issued with immediate rights to services or as a loan type, whereby the service can be accessed upon completion of the infrastructure project.
Additional functionality	**Smart contracts** Smart contracts are an essential part of the platform. During the investment phase of a project, funds are held in a smart contract and reimbursed automatically to investors in the case of insufficient fund collection and resulting inability to start the project or otherwise inflicted failure of the project. Additional features like loans with automated interest payments or insurance contracts can be added over time, enabling the platform to grow in features and adapt to new requirements. It is also possible to automate penalty payments if the project development does not meet previously agreed conditions. Additionally, implemented insurance contracts can be mapped to external events triggering the predefined actions when meeting certain conditions.

3.1.2. Requirements

In order to enable successful blockchain-based financing, the technological infrastructure needs to be provided. For emerging economies, the importance of stable electricity infrastructure and access to the internet from both a platform provider as well as an end user perspective should be emphasised. Validators in the system – initially public and private institutions, and increasingly individual private investors and project initiators – need to have the required capabilities to host blockchain nodes. Investors and project initiators need to have the ability and resources to use internet-enabled devices such as laptops, smartphones or other mobile devices in order to access the platform through either a web browser or a mobile device application. For the purpose of committing and managing the investment, a certain level of adoption of cryptocurrencies should exist. Users need a (fiat) bank account and access to the crypto-tokens. The latter has to be provided by a dedicated blockchain wallet technology. The personal wallet acts as the users' private token deposit.

The customer journey and overall user experience need to be as simple and as convenient as possible, in order for all kinds of investors to be able to invest in infrastructure projects without in-depth understanding of blockchain technology. From an investor protection perspective, mechanisms need to be established in order to mitigate risks of fraud. In this regard, blockchain improves the crowdfunding process with its high levels of transparency, use of smart contracts and scope for enforcement of automatic payments in case of project failures or contract breaches. It is also possible to introduce some form of vetting process for project initiators, especially in an initial permissioned set-up, so that financing platform providers take the responsibility for validating investment projects. Blockchain-based crowdfunding may therefore help to mitigate investment risk more effectively compared to traditional crowdfunding processes.

Project initiators need to be educated on the potential and benefits of blockchain-based crowdfunding platforms in order to take part in the system. This is especially important for small-scale projects that would normally not resort to this form of funding.

Regulators will need to provide a clear legal framework in order for investors to be able to support projects without lengthy lead-up time currently associated with closing investment deals. If legal barriers and complex up-front investment discussions are streamlined and investments are standardised, smart contracts could be used to execute investment transactions. In addition, appropriate screening of the platform and investment transactions will need to be ensured. This is especially important in regards to regulatory aspects in the realm of energy systems and grid resilience, or the prevention of investment flows to countries subject to economic sanctions.

3.1.3. Roadmap

Similarly to blockchain initiatives that can be currently observed in the market, a pilot platform could be established with selected trial members. This pilot could include one or several infrastructure development companies, with international institutions such as the UNFCCC, the OECD, the World Bank or similar institutions helping the coordination of actions between private and government players and supporting related policy dialogue.

After successful pilot transactions, the platform could be deployed and attract early adopter investors. To attract as many early adopters as possible, initial benefits like special discounts could be granted. For companies, on the other side, looking to obtain investments through the platform, several incentives lie at hand: additional sources of financing, exploring new competitive business models, and improved branding. These aspects might lead enterprises to dedicate more resources to developing sustainable infrastructure. If the platform grows in size in terms of available crowdfunding opportunities and the number of investors, it may then become suitable for the full spectrum of projects and investors, from large-scale to micro-investments. Investors could be given the opportunity to securely invest in projects that would normally not be open to crowdfunding due to high administration costs (e.g. funding for a low quantity of solar panels for a local community).

In regards to providing the blockchain infrastructure, public institutions, governments and other public and private entities would need to come together at the conception stage to discuss the main goals and vision for such a financing platform. Identifying and addressing market, legal and regulatory issues and providing an enabling framework for investments from institutions and end consumers alike are essential. Enterprises in the energy, mobility and agriculture sectors should be approached in the early development stages in order to ensure common standards for further scalability. It is also important for regulators to set regulatory and compliance standards early on. There would need to be a clear protocol on

who is able to register as infrastructure project initiator and what rights and obligations the different stakeholders hold.

Once such investment and exchange vehicles have been developed based on a blockchain protocol framework, they can be scaled flexibly on a global level and enhance standardisation.

3.2. Enabling effective carbon emissions markets

With the goal of steering carbon emissions, a certificate system has been defined and established in scope of the Kyoto Protocol and several other settings. In principle, emissions certificates give the holder the right to emit a certain amount of carbon dioxide or other greenhouse gases (EC, 2018a). Under the "cap and trade" principle, a cap is set for the total amount of GHG emissions for a given industry (EDF, 2018). The allowances are usually handed out to companies without charge (a procedure known as "grandfathering"), as companies start trading the certificates amongst each other. Over time, this cap is reduced gradually, so that overall GHG emissions decrease and companies are increasingly steered to invest in climate-friendly technology. Carbon trading can also be partly conducted by "offsetting-certificates". Carbon offsets are realised by financing projects that drive emissions savings and compensate for emitted greenhouse gases (Gilbertson and Reyes, 2009). In relation to this, companies may also create new carbon credits by investing in climate-mitigating projects, such as renewable power plants or reforestation.

Organised in different markets (e.g. the EU emissions trading system, EU ETS), companies are allocated a certain amount of allowances and can trade spare units to companies that would otherwise not stay within their allowance. Buyers and sellers can exchange certificates directly through organised exchanges or through intermediaries, e.g. over-the-counter (OTC) trading or auctioning (EC, 2016).

Emissions certificate systems are viewed as moderately successful. As the most prominent example, the EU ETS showed a steady decline in GHG emissions until 2016, though also registered a rise in emissions in 2017 for the first time in seven years. Although challenges around certificate trading markets still exist, the EU ETS is the only emissions trading system globally that has proven its feasibility and works to achieve the ambitious climate objectives set out by the European Union. An indicator for this success is the carbon price in the EU ETS, which has reached a 10-year high. Other prominent examples of emissions trading systems include the Western Climate Initiative (WCI) and the Regional Greenhouse Gas Initiative (RGGI), both in the United States.

Some challenges regarding the effectiveness of such markets have been pointed out, for example in regards to the over-supply of carbon certificates due to a lack of transparency within the allocation process, leaving companies with more allowances than they need to cover their GHG emissions. This, in turn, alleviates the pressure to reduce emissions and decreases the incentive for companies to invest in cleaner technologies. Security and legal aspects are increasingly significant given the instances of theft of certificates, fraudulent carbon trading, tax fraud and tax evasion within the EU ETS.

In the current set-up of ETS, there are also aspects of general inefficiency. Central authorities can create bottlenecks that could be avoided by implementing decentralised systems. For example, the international transaction log (ITL) connects registries involved in the emissions trading mechanism and validates all transactions before final processing by the national registries (UNFCCC, 2018). Lack of transparency, for example in the total number of certificates available, creates market volatility that could be, at least to some

extent, mitigated through providing suitable technology (Betz, 2006). The EU ETS has undergone reforms to address structural problems (e.g. market stability reserve - MSR), resulting in rising emissions quota prices, but proper further impacts of reform are still to be seen post 2020.

The underlying conceptual challenges deserve careful consideration. Systematic problems and shortcomings of emissions markets, for example that CO_2 emissions allowances have different prices depending on the region and the scheme, can only be solved by political alignment and integrated policies. However, in terms of increasing technological improvement of ETS, blockchain technology can offer tremendous value-added in the areas of global transparency, steering and immutable tracking.

The inception and distribution of certificates on permissioned decentralised ledgers could provide a transparent certificate management mechanism, fulfilling the need for robust carbon accounting. Transactions through a decentralised exchange of certificates could be settled almost instantly, without the interference of any third party. Contractual agreements could also be written and reviewed by a smart contract, automating current manual processes. In essence, it is proposed that blockchain technology can create a more flexible emissions certificate market by virtue of increasing transparency and the efficiency of current trading processes.

There is also an opportunity for blockchain platforms to be linked to treaty-level registries to help support alignment of NDCs, as the Paris Agreement has established the need for a universal, transparent system for measurement, reporting and verification of climate action, particularly related to Article 2.1c and Article 6 of the Agreement.

To illustrate efficiency benefits, a project from the re/insurance industry can be drawn upon. In the similar context of contracting and settlement of agreements across the re/insurance value chain, first tests have shown efficiency gains of up to 30% (B3i, 2018).

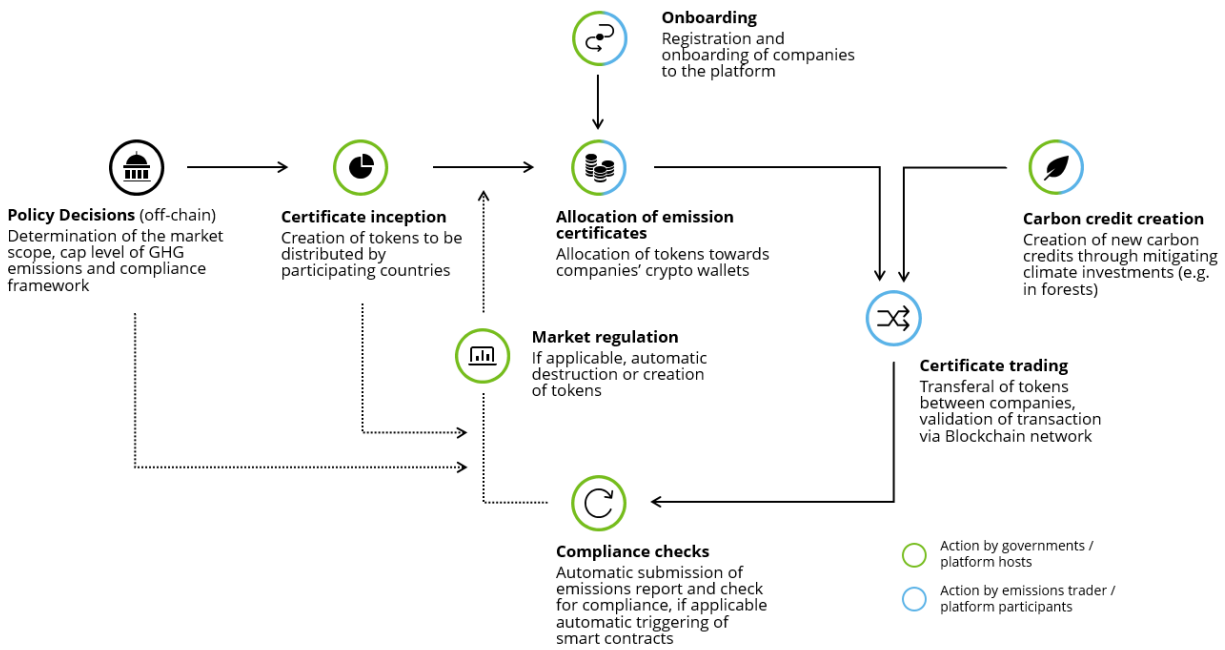
3.2.1. Potential market and technology design

Beyond constructing a suitable market model and the economics of the emissions trading system, the digital infrastructure and its access policies have to be designed. Seen from a technology perspective, there are multiple ways to conceptualise the model and set up a corresponding digital infrastructure. The application layer could create a digital platform that manages identities (e.g. private corporations), emissions quotas, and the certificates themselves. The blockchain layer thus acts as the transaction layer and immutable book of accounts for certificates.

The blockchain network may be hosted by the responsible public organisation (e.g. Ministry of Digital Infrastructure) on a government level. These nodes in the network could be mandated to validate transactions and maintain consensus of the certificate registry and circulation. All participating corporations, hence the public and private organisations that purchase or receive allocated certificates, could join the network via an application. Accordingly, these actors engaging the platform would not validate certificate transactions.

Figure 6 illustrates how an emissions certificate trading cycle could be represented on the blockchain.

Figure 6. User journey for regulators and companies for blockchain-based emissions trading platform



Source: Adapted from "10 practical steps to create an Emissions Trading System" Guigon P. (2016), https://blogs.worldbank.org/climatechange/10-practical-steps-create-emissions-trading-system.

In the initial step of scoping, capping and further regulatory requirements are decisions made "off-chain" (Guigon, 2016). Once all regulatory, compliance and administrative requirements are set, tokens representing quotas of emissions could be created on the blockchain and held by the responsible regulatory authority of each participating country. Covered organisations in the private and public sector could then be registered and (digitally) on-boarded to the platform. Their respective quota might be allocated by transferring the appropriate amount of tokens via a smart contract-triggered transaction.

Using these tokens, companies would be able to trade the emission certificates via applications as known from today's commodity or stock exchange trading systems. This could also be extended towards other trading methods prevalent in the EU ETS, such as auctioning and OTC trading. Blockchain-based solutions for OTC trading have been proposed on the market to improve efficiency and lower transactions costs.

By investing in climate mitigation projects (such as forests and wetlands), companies might also be able to generate new carbon credits, which could be traded on the platform, providing in turn a source of revenue for the preservation of natural capital.

A key benefit of blockchain lies in the cutting out of lengthy verification processes and intermediaries through timely consensus and transaction settlement. This would also be the case for international emissions trading, linking different markets (e.g. between the EU ETS and the Swiss ETS) by eliminating many of the standardisation issues currently faced by ETS (e.g. registry designs, compliance periods), although some conceptual problems need to be addressed regardless of the technology used (e.g. nature of cap, offset provisions) (Kachi et al., 2015, European Council, 2018).

Table 4. Possible technical set-up of blockchain-based emissions trading platform

Design factor	Selected types and their functionality
Consensus mechanism	**Proof-of-authority (PoA)** Selected and validated participants (government entities) will create the network and run the consensus mechanism as PoA. This ensures security and regulatory integrity of the network. New validators can be on-boarded over time, however, there should be a clear policy on which government entities can join the project and under which circumstances. Due to the binding force of the respective treaty, governments and potentially nominated NGOs should act as the only validators in a proof-of-authority set-up. Companies covered by the trading scheme can participate and trade emissions certificates, however they would not participate in transaction validation on the platform.
Privacy	**Permissioned blockchain** The blockchain underlying the platform should be set up as private. As the platform should be operated by various governments, limited numbers of participants need to be selected and validated to take part in the validation process. By setting up a private blockchain with only registered governmental stakeholders, policy changes such as the reduction of the global cap of emission certificates can be conducted.
Hosting	**On-premise** The preferred hosting solution is on-premise in order to ensure maximum security in the decentralised network. Each government should host a node in their own premises. Due to the data sensitivity and increased risk of attacks, cloud and third party hosting are not advised.
Tokenisation	The underlying blockchain can be both data- or coin-based. A hash could be created of an existing emissions certificate, which could then be documented on a data-based blockchain. Certificates could also be tokenised so that fractions of emissions certificates could be traded on a coin-based blockchain. This creates a micro-economy and enables a market within the platform.
Additional functionality	**Smart contracts** Compliance rules can be written into smart contracts and automatically executed in case of requirement fulfilment. This way, processes can be triggered automatically without interference of an observing intermediary, making the overall process more efficient. For example, fines could be automatically imposed if emissions certificates do not cover emitted GHG for the compliance cycle. **Oracles** Oracles can be used to measure actual emission of GHG and mapped against emission allowances of companies. This provides information to the smart contract if requirements have been fulfilled or if a penalty should be imposed.

At completion of a cycle, compliance checks including reporting and verification processes would need to be conducted. For instance, in the case of EU ETS, companies are required to submit an emissions report, which is reviewed by an accredited verifier acting as an independent third party (PTPA, 2017). The described blockchain network would provide the means to further automate and increase transparency in this verification process. In addition, emissions monitoring can be enhanced by deploying measurement hardware that is already natively connected with the blockchain layer. A similar model has already been developed in the context of self-driving cars where secure sensor data are transferred with a blockchain-link.

In cases where a non-compliant activity is recorded by the authorities, automated payments, penalties, caps or similar methods could be enforced through smart contracts as well. For example, companies could automatically be fined a certain amount if their acquired allowances do not cover their emissions for the compliance cycle (EC, 2016). ETS performance and compliance could therefore be easily tracked.

After completion of a trading cycle, the aforementioned processes from political decision-making to compliance are repeated in order to start a new cycle. At this point, it is possible to establish revised political requirements, for example when decreasing the overall amount of emissions certificates in order to reach the set climate goals.

In terms of technical set-up, blockchain technology offers the needed flexibility to coordinate and execute certificate trading transactions. Table 4 summarises a possible technical set-up based on the outlined trading cycle. Given blockchain technology's nascent state of maturity, several factors may have to be adjusted while developing the technology together with the stakeholders.

3.2.2. Requirements

The two main stakeholder groups are governments acting as regulators and network validators, and organisations covered by the emissions certification framework that participate in the market.

The most critical requirement for a successful implementation and operation of the trading system is the design of the market economics. Referring to today's shortcomings of the trading market, policy makers need to update the cornerstones of such a system. Markets that include the definition of caps and allocation of allowances, streamlining of processes, requirements and penalty schemes, are key factors, to name a few.

Seen from a technology and blockchain network perspective, governments will act as regulators in the system and validators in the blockchain network. Hence, nodes need to be set up and operated, which requires a minimal digital infrastructure with stable electricity supply, database technology, and broadband internet.

Participating companies covered by the trading model interact with the platform via applications and edge devices (e.g. pollution sensors), which requires access to stable electricity and internet. An intuitive user interface is needed for the platform, so companies can easily trade their emissions certificates without the need to fully understand the underlying technology. However, companies will need to be educated thoroughly on processes, penalties, compliance cycles and other underlying concepts and procedures of the platform. This is especially important since the trading platform must have a legally binding character.

3.2.3. Roadmap

The blockchain solution will lead to a shift from fragmented registries to a decentralised, but synchronised network. This shift is highly transformational and requires significant investments in terms of time, education and resources. In order to facilitate this change for both regulators and participating companies, a gradual adoption model is proposed in the following figure.

Figure 7. Roadmap towards blockchain-based emissions trading system (ETS)

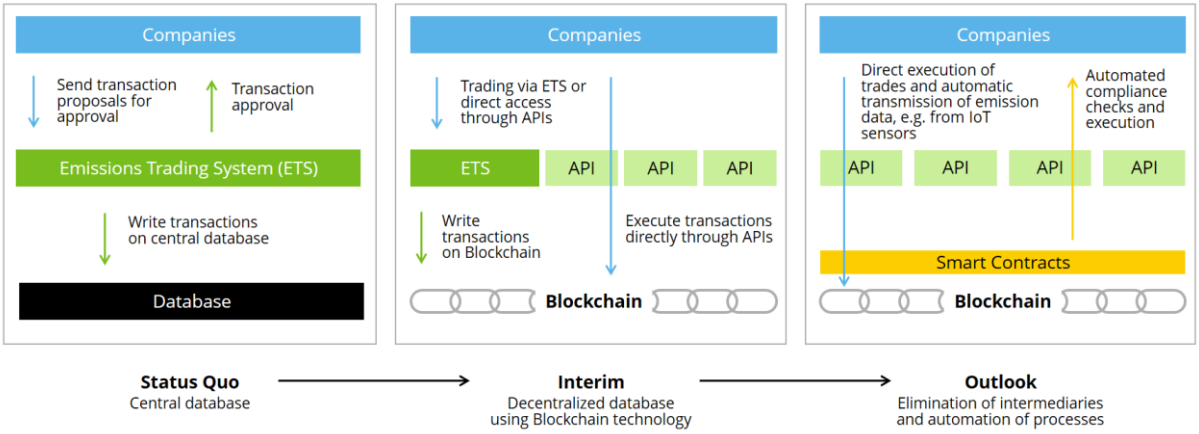


Figure 7 illustrates a proposed gradual shift towards the use of blockchain technology. In the first step, existing processes would remain the same, but the underlying data is captured by mapping the hashes on a blockchain rather than a centralised database. This way, all established processes and procedures stay in place while the benefits of blockchain around transparency and immutability still create value. Through application programming interfaces (APIs), companies are empowered to have full insight into all of their transactions.

The procedure can be applied to all existing emissions trading systems. In order to link geographically dispersed systems, the standardised underlying blockchain infrastructures can be connected over time. The prerequisite for this is that policies for different markets can be interlinked or aligned, which should be achieved before interlinking different ETS.

In scope of updating the emissions market in the realm of new policy agreements, a viable transition roadmap has to be defined. New trading applications and increased degrees of automation can be opened up for engaging parties, while robust carbon accounting can be rolled up to regional and national levels. For instance the tracking of internationally transferred mitigation outcomes (ITMOs) provides a means for transparent technical and expert reviews, preventing double registration, while automating processes using smart contracts (GHG Protocol, 2018). Article 6 of the Agreement can thus be operationalised in a virtual environment. With established players like the Energy Web Foundation, important steps have been made towards developing the suggested platform. Collaboration between the UNFCCC, participating governments, renewable energy developers and buyers, and other private and public institutions could lead to an accelerated deployment.

Looking further into the future, IoT devices and sensors could be installed at the source of pollution, acting as secure oracles by cryptographically sealing and uniquely tagging the data at the source and sending it directly to the blockchain ledger. By implementing, monitoring, and reporting services based on data stored on the blockchain, real-time emissions reports would not need to be quasi-manually validated by independent third parties.

3.3. Alignment of infrastructure development through blockchain-based infrastructure contract management systems

Infrastructure construction projects frequently involve many contractors (e.g. client, prime contractors, several subcontractors, etc.), who deliver services based on complex and long-term contracts. In long-running infrastructure construction projects, legal uncertainties arise regarding the validity of contracts or the status of negotiations. The more parties that are involved in contracts, the more time-consuming and costly the contract documentation and orchestration of the stakeholders becomes. Additionally, in the course of construction, the involved parties modify contracts quite often, for example by extending the contract or splitting it into smaller more complex contract landscapes. Mutual agreements might lead to changes of existing parts of the contract itself. Another key driver is regulatory changes that need to be implemented and require adaptation of existing contracts, as a handover using the existing agreements might be *contra legem*. Furthermore these changes might be interpreted differently by the involved parties, requiring multi-party alignment.

A look into practices shows that there are a significant number of versions of contracts, resulting in confusion around the agreed upon contract conditions at a specific point in time. There are a number of reasons for this. A lack of transparency in the agreements (regarding specific contract sections or the contract as a whole) is one of them. In this context, operational and legal problems often arise, which consequently also lead to higher project costs. Contractual fines are often a source and driving force for legal disputes concerning which version of a contract was valid for a specific point in time.

There have been various examples in the realm of public infrastructure construction projects, which illustrate the consequences of a lack of contracting transparency. In the construction of the Berlin Brandenburg Airport in Germany, lack of governance and complex contractor agreements have led to a cost increase from the originally estimated EUR 2.0 billion to approximately EUR 7.3 billion, delaying the planned opening of the airport for several years, while triggering hefty contractual fines (Fiedler and Wendler, 2015, Jarvis, 2018). Another example is the expansion of the Panama Canal and its cost overruns and delayed completion, which has also partly been attributed to its interrelated and multiple contracts (Robertson et al., 2018). In Vietnam, the government and developing partners have focused efforts specifically on improving contract management of civil work contracts and related processes and systems in order to enable development that is more effective (Tran and Nguyen, 2015).

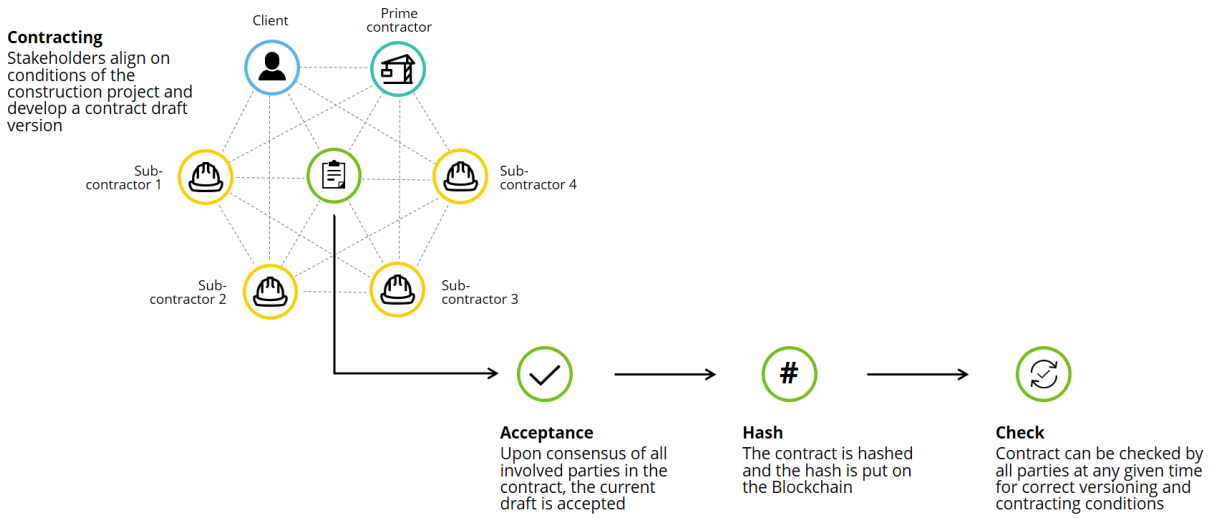
Contracts are currently often circulated via e-mail between contracting parties. Document management systems (DMS) are also sometimes used in order to draft, review and accept contracts. Often, if there are larger project consortia, one independent and assumed neutral company or the biggest stakeholder is responsible for contract management. The responsible party for contract management sets up the technology and acts as the administrator with access to all data and the possibility to change the status of documents. One of the most prominent examples of a DMS is SharePoint, which is used in companies to share digital documents (Microsoft, 2017). In the case of a legal dispute, the assumed neutral party may place its own interests ahead of others, making it a poor choice to serve as the central intermediary. Consequently, many challenges can arise with these contract management set-ups, such as having a single point of failure in terms of technology, the need for a trusted (external) entity or intermediary, and information asymmetry between stakeholders.

Blockchain technology can significantly improve contracting of public infrastructure projects by providing transparency in the contracting process as well as establishing a single source of truth on current contract agreements. By adopting such IT systems, involved parties can profit from certainty of which contract version is valid, and can review the conditions at any given time. In the following, a blockchain-based multi-party contract management system is introduced, which spans the whole contracting lifecycle.

3.3.1. Potential market and technology design

In order to provide a trusted single view on multi-party contract arrangements, contracts and their drafts are documented on a decentralised ledger. As illustrated in Figure 8, all relevant parties, including the client, prime contractor and all sub-contractors align and agree on the latest conditions to be determined in the contract.

Figure 8. Process of blockchain-based contract versioning



The key concept behind this is to use blockchain / DLT to achieve an additional set of integrity. The main challenge here is to balance the need for proof, which involves transparency and the need for data privacy. With legal documents the threshold for data privacy is one of the highest possible. It would therefore not only be not advisable, yet simply not allowed, to upload legal documents onto the blockchain. This does not only hold for the documents, but any metadata that would allow drawing conclusions about the contract at hand. A good mix of on- and off-chaining, i.e. to only store parts on the blockchain, and of a hybrid use of public and private blockchain, can address the fundamental conflict. To break this into concrete concepts: One approach is to calculate a hash value for each contract version and only store this on the blockchain. By hashing each version of a document and submitting that hash to the blockchain, ideally a public blockchain, e.g. Ethereum, each party is in a position to prove in case of litigation that a certain version of a document has been agreed upon and handover that document. The hash value can be easily compared to the value stored on the blockchain.

All versions of a contract are archived in a DMS and connected to the legal workflow management. Upon agreement of all involved parties on the latest and legally binding version of the contract, a hash is calculated and added to the blockchain. Based on the

documented hash, there is a single source of truth concerning the validity of contractual agreements, which is immutable and transparently examinable by all involved parties at any given time.

Figure 9. Functional architecture of blockchain-based contract versioning

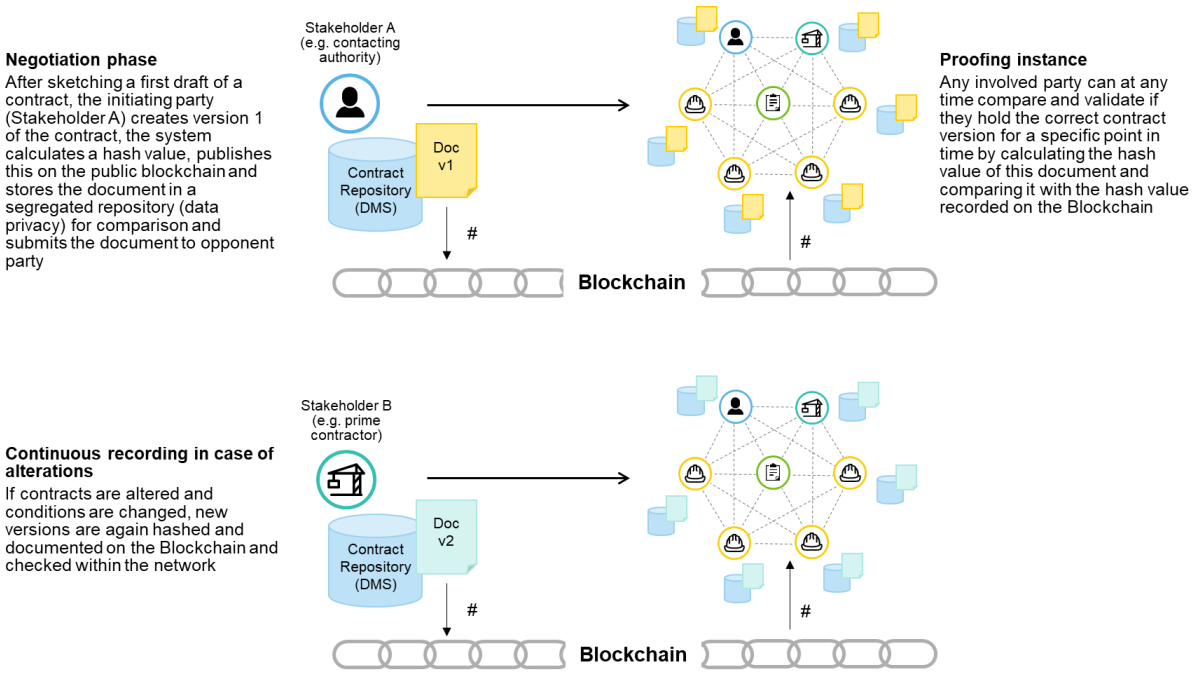


Figure 9 depicts the functional architecture of the solution. Here only the hash value is stored on the public blockchain. Any other necessary metadata, e.g. version number, submitting username, project name, is then stored in a private blockchain or off-chain, depending on client's preferences. By strictly separating sensitive data from the hashing value, a low entrance barrier is secured, no contract contents are publicly visible and it enables scalability. The additional levels of integrity in this potential setup are an added value in themselves for stakeholders.

Although the main idea of a blockchain-based infrastructure contract management system is to provide transparency and a timestamp on contracts in multi-party engagements, the concept holds great potential for further development.

For example, rather than only documenting the hash value of "offline" contracts, the whole agreement could be translated into code and implemented on the blockchain for more automated execution. In this case, systematic rules are defined by the participants and can be implemented as smart contracts on the blockchain. This can be especially useful in cases of handover of a specific part of construction. If the pre-defined requirements are fulfilled, the smart contract is executed automatically. To give an example, the engagement between the main contractor and a sub-contractor could be automatically extended if the sub-contractor meets all pre-defined requirements in the agreed timeframe.

Taking the idea of automation further, future financial transactions could also be made possible through a blockchain-based contract management system. A cryptocurrency or token could be created and used to settle payments between the parties. For example, if

contractual agreements are breached by one party, fines could be automatically imposed on the responsible party.

From a technical perspective, two components of this contract management system need to be distinguished. The DMS can be any kind of application used to collaborate on contracting; these systems are already used today in order to jointly work on contract drafts. This DMS then needs to be connected, for example through APIs, to an underlying blockchain in order to document the hashes of the latest legally binding contract agreements. Table 5 discusses the technical set-up of the underlying blockchain layer. In order to keep the entry barriers low, there is only a small core of the architecture, including a web interface and the blockchain as a backend. No DMS is connected by default. Hence, each party can use its own contract creation tool. If a DMS is not used, a plain word processing tool like MS Word could be used instead. With this approach, different heterogeneous systems can connect. This approach differs to traditional contract creation tools, where all involved parties have to agree on specific tools with the consequences that additional software needs to be installed if it is not a pure cloud solution.

Table 5. Possible technical set-up of a blockchain-based infrastructure contract lifecycle management (CLM) system

Design factor	Selected types and their functionality
Consensus mechanism	**Proof-of-work (PoW), -stake (PoS), notary nodes** Although it is good to be technology agnostic towards various blockchain protocols, advocating to use public blockchain protocols to achieve the highest possible level of trust and integrity is good practice. Ethereum is currently the best choice as it is mature enough and has a good support for smart contracts. Ethereum in its current implementation is using PoW, but its upcoming Casper implementation will include a switch to PoS. Other promising protocols like IOTA are upcoming, but are not yet mature enough for production. Furthermore, in later stages of CLM hybrid solutions are in discussion, i.e. submitting the hash value on the public blockchain, while keeping sensitive metadata and the documents themselves in a secured permissioned-only private DLT like Corda. Here the consensus mechanisms are notary nodes, and various consensus algorithms can be used depending on client preferences and requirements.
Privacy	**Permissionless blockchain** The highest level of trust and integrity is a public blockchain. The hash value does not contain any information that could lead to the content of the underlying contracts. The public blockchain will stay in operation, regardless of any development of participating stakeholders. Hence, it is possible to retrieve the hash values years after archiving the contracts.
Hosting	**Multiple options** Hosting is not limited to one option; on-premise, cloud and third party hosting are possible. Depending on data sensitivity, costs and the data protection guidelines of each participating company, it might be preferred to store sensitive data at each participant's site on-premise in off-chained storage facilities, e.g. databases or DMSs or on-premise private blockchain nodes in case of later stage hybrid solutions.
Tokenisation	**Depending on set-up**

Design factor	Selected types and their functionality
	In the initial set-up, it is intended to only store the hash values in the public blockchain due to strict data security and data privacy requirements. The data that is transferred using the system is not based on a coin of any kind. In case of future hybrid solutions, i.e. storing the hash value in the public blockchain and meta data and / or the documents themselves in a secured private blockchain, moving to the private blockchain could be accomplished using data-based tokens. As the system matures, it is possible to create a cryptocurrency, which can be used to settle payments stemming from the contractual agreements; stable coins pegged to fiat currencies like Euro or Dollar could also be realised on a coin-based blockchain.
Additional functionality	**Smart contracts** Over time, the multi-party contracts could also be translated into code and put on the blockchain for automation purposes. Rather than solely hashing an existing contract, specific rules like handover criteria defined in the underlying contracts are then put into algorithms and submitted as smart contracts to the blockchain. Upon fulfilment of those pre-defined conditions, the smart contracts are then automatically executed. Another goal for future releases is a compliance check for BIM conformity.

3.3.2. Requirements

In order to run the infrastructure contract management system, the participating companies would need to be on-boarded and educated about the underlying technology. The on-boarding efforts in the depicted process and architecture are rather minimal compared to the set-up of current solutions.

In case participants wish to further automate processes and want to use a private blockchain for the contracts themselves in addition to the public blockchain, which only stores hash values, it might be necessary to ensure that users have the capabilities necessary to host nodes. They might also need to be knowledgeable about their specific requirements regarding data protection if they decide to host their nodes using third party providers.

The contract management system does not necessarily require a connection to a DMS. As many companies already use various systems to draft contracts and share versions with each other, it is most feasible to integrate existing DMS with an underlying blockchain layer through suitable APIs. The user interface needs to be intuitive and easy-to-use, as a wide range of users from business to legal departments of infrastructure project initiators, contractors and sub-contractors will need to use the system in order to review, accept or modify contractual agreements.

The joint development and documentation of contracts gives the opportunity to achieve some degree of standardisation. Master service agreements, contract terms, modifications, extensions, appendices, etc. can be processed in similar ways by the involved parties in order to avoid errors or confusion. As an example, the building information modelling (BIM) guideline in Germany is to be implemented until the year 2020, aiming to collect relevant information of a building's lifecycle in order to ensure transparent communication of all stakeholders (Bundesministerium, 2017).

The focus of CLM lies at the tangible added value for the user. The visualisation of the versioning without a central counterpart creates an eco-system without any vendor locking.

3.3.3. Roadmap

The blockchain-based contract management system could be developed in a pilot project. This could be set up in parallel to existing and current infrastructure developments, for example within smart city projects. Within the pilot, blockchain-based contract management systems and assets already under development could be leveraged and tailored towards specific needs, for example in regards to industry standards, legal and regulatory matters or user experience. This approach enables a real-life trial of the system while further developing the solution.

Big infrastructure project initiators could be involved in early pilots. Since they tend to develop several projects at a time, they can quickly achieve efficiency gains by taking part in the pilot, rolling out the developed system in their other engagements. As more and more infrastructure developers, contractors and sub-contractors participate, the blockchain-based contract management system could become a driver for increased standardisation and automation in the infrastructure sector. Similar to the environmental, social and governance (ESG) standards that are applied in infrastructure investments, a blockchain-based contract management standard could also be developed as additional consideration for infrastructure development projects.

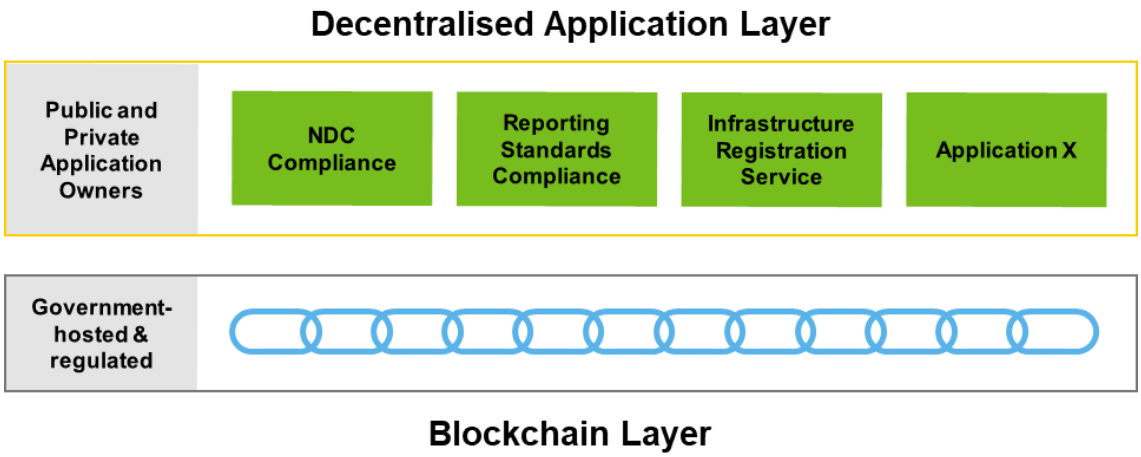
3.4. Global action and infrastructure monitoring platform

In order to assure compliance with the overall goals of standards for infrastructure across the value chain, which could include standards related to environmental, social, and governance (ESG) criteria, an increased effectiveness in the timely analysis and decision making of policy and investment options is needed. Implementing the right measures for global infrastructure-related action (e.g. financing, certification, reporting and compliance) requires decision makers to have access to genuine, standardised and up-to-date information. However, today's persistent operational challenges, especially in regards to transparency, auditability and interoperability of data, result in inefficient processes and unaligned activities. To overcome these challenges and to set up a sustainable, highly interoperable and trust-inducing data backbone, blockchain technology provides a viable approach.

The envisioned platform does not depict a global database of infrastructure-related data. On the contrary, it may act as a horizontal operating system spanning an overarching trust layer on the existing digital and physical infrastructure (Deloitte, 2016).

The jointly provisioned blockchain layer could drive an auditable, immutable, and efficient aggregation of relevant data in the realm of sustainable infrastructure. Authorised stakeholders, such as national regulators in the transport, energy and agriculture sectors, would have the opportunity to build suitable applications on the blockchain layer, therefore enabling them to leverage existing and compliant technology. Figure 10 schematically illustrates the horizontal operating system encompassing a modular application layer. In regards to the many different applications and industries, where such a blockchain solution could be used, there may also be a need for many chains that integrate with each other and therefore work together. Separate blockchain layers for different purposes could be built on the foundational blockchain layer as well. As examples, the case studies described in 3.1 and 3.2 could be built on top of the foundational blockchain layer.

Figure 10. Schematic illustration of the envisioned two-layer architecture



The increased harmonisation of the systems landscape, as well as the interoperability benefits and process efficiency gains, would greatly support national organisations such as ministries and their infrastructure and budget planning departments. Taking decisions based on data provided by a comprehensive and trustworthy infrastructure and project registry layer would allow for better decision-making and cost savings.

Introducing such a deeply embedded data sharing service could consequently enable decision makers to better align, plan and track investments and related financial flows on a global, national and regional scale through the whole value chain. For financing of infrastructure, for example, a single source of truth is established from analysis of project feasibility, tendering and procurement of a suitable infrastructure developer, to construction and post-construction financing and operations. In this way, all participants of the value chain are provided with the same validated data at the same point in time, so there is no trust needed between the stakeholders.

Private-public direct investment activities and jointly provisioned funds such as the Green Climate Fund (GCF) could be linked to the network, enhancing their impact on contributing to climate goals. Interfaces with related organisations of the private and public sectors can be uniquely identified, and monitored throughout the network. Measures such as embargos, specifically complex sector-based embargos or special tariffs and limitations, could be depicted on the network and therefore ensure that invalid transactions cannot be triggered by one party. The full transparency provided by blockchain would make the processing of forged transactions very difficult and corrupt corporations and officials would face significant restrictions in misallocating funds.

In addition to the main advantages resulting from the integrity and auditability of data used to make decisions across all sectors, process efficiencies could be obtained by using a blockchain layer. As mentioned in section 1.2, smart contract functionalities, and the native integration of IoT devices (e.g. sensors, mobile devices, cars) throughout all levels of the value chain, would enable an advanced degree of integrity and automation. Contractual information and agreements, such as nationally determined contributions (NDCs), investment agreements, or service agreements (e.g. research activities or emission audits), can be implemented on the self-enforcing network.

Reporting standards and processes could also be made more efficient by leveraging this blockchain layer. Data needed for reports in specific sectors could be provided

automatically and transparently via blockchain tracking. In this regard, blockchain solutions have been proposed for the shipping sector in the EU, which is by law required to monitor, report and verify (MRV) CO_2 emissions, fuel consumption, and other parameters from each ship using EU ports. By combining IoT and blockchain, this data can be tracked easily and immutably, increasing efficiency in the MRV process (EC, 2018b).

3.4.1. Potential market and technology design

As depicted in Figure 10, the platform logic can be described by a two-layered architecture. The blockchain layer is the base protocol, which defines the overarching consensus and validation mechanism, as well as smart contract and wallet standards. Building on the natively integrated and network-wide enforced transaction logic, an endless variety of applications can be developed. The blockchain can hold hashes to the original data points, which are solely managed by the related organisations. This set-up provides a high degree of flexibility by reducing the amount of data distributed on the network. Consequently, an unfeasible and unsuccessful deployment of the decentralised IT-infrastructure can be mitigated. Organisational efforts in implementation activities and associated costs could be reduced as well.

The interoperability between existing applications, mainly related to token and data exchange, as well as access policies can be maintained by special interfaces. A multitude of applications provided by unrelated organisations globally can be interconnected, whereby trust regarding the underlying transaction data can be maintained across the network. For example, two distinct applications such as an automated monitoring of infrastructure compliance, and a management service for disaster recovery funds can be operated on the same protocol by different mandated application owners.

Each blockchain network participant may share specific information on infrastructure projects in a standardised, secure and efficient way without compromising data sovereignty. By leveraging the decentralised network, parties benefit especially from immutable data traces, efficient management of transactions and audits stemming from multi-party relationships and complex partnerships. Long-term / life cycle contracts and partnerships, joint funding, and similar business processes between parties can be transparently tracked and managed. Several concepts and technical prototypes have already been developed. For example, a concept for a blockchain-enabled reinsurance platform has been proposed, which reduces errors, costs and duration in the contract management process for disaster events (Deloitte, 2017b).

In order to realise such a comprehensive platform, amongst others, current operational databases that encompass the required information have to be integrated efficiently with a newly developed blockchain layer. Modern database technology's interoperability with blockchains is generally given and performed by using standardised interfaces. Oracles, as described in section 1.2, represent data sources outside the blockchain layer that are cryptographically connected to the network. Existing national registries of, for example, decentralised power plants (e.g. solar), or electric vehicle fleets, may well be mapped on a blockchain layer with the required information for global monitoring and reporting services.

The proposed platform can be designed in a multitude of constellations. Primarily given the fast changing maturity of protocols and interfaces, the platform must maintain a high degree of flexibility by comprising clearly defined modules. In order to cater to the requirements best while balancing efforts and costs of operating the platform, the following initial design is proposed. Table 6 summarises the suggested technical aspects.

Table 6. Possible technical set-up of the global blockchain-based monitoring platform

Design factor	Selected types and their functionality
Consensus mechanism	**Proof-of-authority (PoA)** The consensus mechanism for the platform is PoA, which gives any validator in the network the possibility to write new blocks in a pre-defined order. Validators are the entities that initially create the network, for example the UNFCCC countries. Since probably not all countries will participate from the beginning, new joiners can be granted a right to participate in the validation as well, if agreed upon by the existing members.
Privacy	**Permissioned blockchain** The blockchain will be designed as a permissioned blockchain, granting access only to white-listed entities. These entities will initially be all the validators that create the network plus all parties that are involved in the first phase. As the network grows, more parties can join the network if all the validators agree on it using the PoA algorithm.
Hosting	**On-premise hosting** Since the network spans only a few selected entities, hosting must be highly secure and tamper-proof. Therefore, an on-premise hosting in all participating countries is suggested. This means that those countries have to define a ministry that is able to securely host a node to participate in the validation process.
Tokenisation	**Data-based** The data that is transferred using the system is not based on a coin of any kind. Therefore, it is not necessary to have a base-coin in the system to map the data. As all validators, in their roles as governmental bodies, are defined and by design incentivised to participate in the process, no monetary incentive for validating new blocks is necessary. Specific coins for use cases could be created as applications on top of the platform, enabling those applications to create their own crypto-currency.
Additional functionality	**Smart contracts** Smart contracts are the base functionality for all the logical structures that are put in the network. This means that real-life contracts between any kind of entity are stored and digitally represented, including automated actions like the blocking of funds for certain reasons. This creates an ecosystem for any sort of application. **Oracles** Oracles can be used to provide external information to the smart contracts and therefore to the applications based on the platform. The framework offers standardised methods to include oracles, so using them is a base-function and therefore simple. This way, it is easily possible to include any kind of external information that is necessary to execute the application, enabling multiple efficiency use-cases. It is important to decentralise the oracles as well so that there is no central external database that can manipulate the whole network.

3.4.2. Requirements

Seen from a basic infrastructure perspective, the suggested platform and participation as a blockchain node require stable access to the internet. Given the suggested consensus algorithm proof-of-authority (PoA), running the validation procedure does not require a node operator to provide resource-intensive hardware or energy. Regulators would have to design a framework, with a governmental institution being responsible for hosting a node. Whereas in advanced economies a dedicated ministry of digital infrastructure is in place and can host a node, it would be important to support developing countries with adequate organisational and technological infrastructure to implement the system.

Users of the applications, for example national organisations responsible for climate reporting, would equally require stable access to the internet and depending on the use case, access to an appropriate edge device, such as regular computers or mobile devices.

For a successful implementation and operation of the platform, it would be important to maintain a high degree of flexibility in integrating currently operational database systems via APIs. Assuring interoperability would require the architects and developers of the blockchain layer to be knowledgeable of related database technologies and commonly used data structures. Critical security and privacy requirements of each key stakeholder, e.g. energy and transport regulators, digital infrastructure regulators, financial institutions, would have to be considered in the design as well. It would be very important to maintain the decentralisation when adding external systems, so that all the APIs need to be decentralised as well, creating multiple entry-points to the system and therefore not centralising it by just having one possibility.

Moreover, the acceptance from targeted platform users (i.e. public and private organisations, and their functional and technology practitioners) in the realm of infrastructure would have to be assured. A proven way of gaining buy-in from users and developers is to provide a best-in-class experience and ease of access for developers as well as for the end users. Observing similar digital platform systems, such as major e-commerce services or car sharing platforms, the network effects generated by transactions between many users represent the key to success and drive value of the platform. Yet, due to blockchain technology's current state as a developing technology, there is scope for improvement in its accessibility and user-friendliness. A number of start-ups are already addressing this challenge by developing applications that reduce the burden of adopting the technology in existing systems and business processes.

Accordingly, it is suggested that a comprehensive, up-to-date and transparent documentation be provided to the stakeholders. In order to increase the potential for success and trust in the platform's integrity, the source code related to the blockchain layer could be made available to the wider public via open source license models. In this way, public and private organisations would have simplified access, and be able to implement flexible measures to become educated in the technology.

3.4.3. Roadmap

In order to design, develop and implement the suggested platform, several key prerequisites are necessary from an organisational, as well as technological perspective.

Facing the challenge of setting a commonly accepted standard in the protocol layer, an intergovernmental consensus would have to be achieved. Only if all future users understand and accept the technology framework that defines consensus, can trust be maintained in the network. Consequently, participation and commitment has to be incentivised by clearly

showing the significant benefit for all stakeholders. Since the private sector plays a key role in the low-carbon transition, their disclosure and compliance in infrastructure development and provision has to be secured. Engagement on the platform via applications will provide significant benefits, yet, these have to be transparently communicated and sufficiently proven. A healthy balance of extrinsic regulatory incentives and intrinsic motivation can induce buy-in for the private sector to join and foster the platform.

The envisioned global blockchain layer may be best initiated and developed by a dedicated working group or task force mandated by governments. Existing data standards from private and public sector initiatives, including the collection of financial and ESG data on infrastructure performance, could be integrated into the process. The mandate will allow an effective approach to building the necessary relationships and generating buy-in from treaty-level stakeholders, national organisations and regulators, technology partners, and research contractors. The proposed working group, consisting of practitioners with blockchain technology and process expertise, would have to be established and sufficiently mandated to develop an initial architecture and operating model of the platform.

Looking at today's landscape of blockchain-based projects and services, it becomes evident that the nascent state of maturity and scarce availability of technical practitioners will require the working group to engage key industry consortia, alliances and independent start-ups to build sustainable partnerships. Engaging the private sector and supporting start-ups in developing technology for the suggested global platform would contribute to innovation and increase awareness of technology's role of enabling the low-carbon transition.

Accordingly, it will be important to design a suitable governance model for managing the communication and development effort. Existing frameworks employed by organisations or related institutions for similar requirements may be adapted and implemented, which can greatly increase speed and reduce costs and the risk of failure.

4. A roadmap for blockchain implementation and pilot programmes

In discussing possible use cases for blockchain in regards to infrastructure, it is important to keep in mind the process of setting up blockchain environments, taking into full account the business case as well as technical set-up. As mentioned in Box 1, blockchain projects tend to be developed within consortia due to the network nature of the technology. Consortia usually consist of a group of companies and partners, such as technology providers, but may also include regulators or other relevant institutions. It is beneficial to develop pilot programmes for blockchain applications that bring together the main stakeholders, as many additional topics need to be agreed upon (e.g. legal set-up), which are unique to consortia work.

Pilot implementations, meaning implementations with a product and business ecosystem limited in scope and features, are an effective way to test blockchain products in a smaller scale before deciding to propagate into a live operation phase and further develop the solution. In the blockchain space, pilots generally consist of three phases: the **design phase**, **implementation phase** and **operation phase**. As shown in Within the design phase, the overall goal is to identify, describe and set guidelines for the planned blockchain solution and consortium. In the beginning, workshops should be conducted between cross-functional stakeholders and specialists in order to discuss the most pressing issues, where blockchain can pose a valuable solution. The hypotheses developed within these workshops should then be tested and verified through extensive research, potentially including surveys of intended target groups. Implementation costs should be estimated, along with alternatives, comparing also to the status quo: it is important to determine early in the design phase whether a blockchain application is value-adding to its intended use case. By developing a prototype, technical and functional feasibility of the concept can be tested, and the application can be demonstrated to stakeholders. If the general concept for the prototype is approved by all decision makers, initiation of the business ecosystem of relevant stakeholders can start.

Blockchain implementations are unique in the sense that they operate in a network, often times as a consortium. Not only do the consortium participants need to decide on the type of blockchain solution they want to build, but they also need to agree on adjacent issues before going further into development of the solution. Often times, the most pressing question is around legal set-up and guidelines of collaboration. For example, agreement needs to be reached on which legal form should be chosen for initial and future collaboration, who is contributing how much in investment and resources, how governance of the project should be set up, or who owns the intellectual property created during the project. Once these decisions are made, the teams consisting of individuals from various partners or even external parties need to be brought together and mobilised for development.

Figure 11, various scopes and activities are connected to each phase.

Within the design phase, the overall goal is to identify, describe and set guidelines for the planned blockchain solution and consortium. In the beginning, workshops should be conducted between cross-functional stakeholders and specialists in order to discuss the most pressing issues, where blockchain can pose a valuable solution. The hypotheses developed within these workshops should then be tested and verified through extensive research, potentially including surveys of intended target groups. Implementation costs should be estimated, along with alternatives, comparing also to the status quo: it is important to determine early in the design phase whether a blockchain application is value-adding to its intended use case. By developing a prototype, technical and functional feasibility of the concept can be tested, and the application can be demonstrated to stakeholders. If the general concept for the prototype is approved by all decision makers, initiation of the business ecosystem of relevant stakeholders can start.

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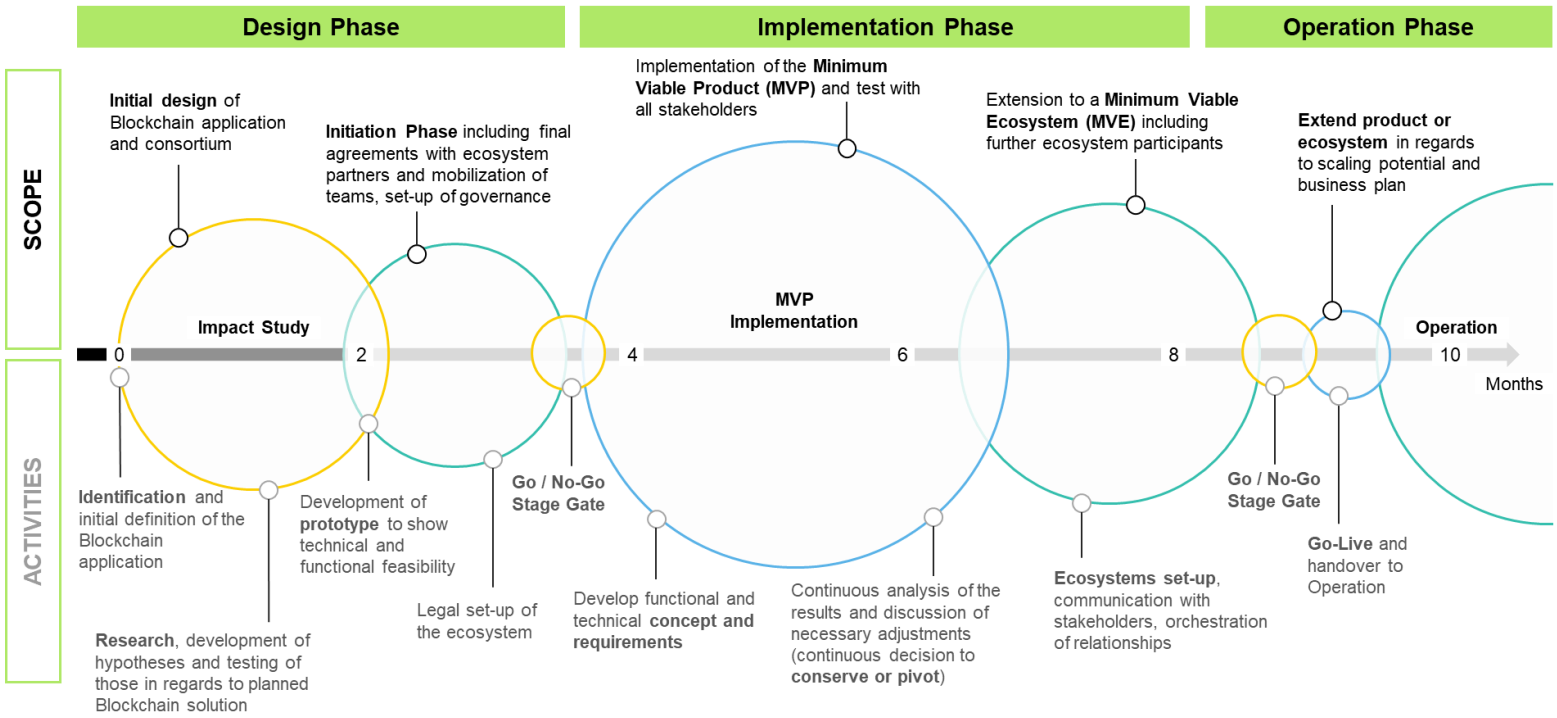
Figure 11. Roadmap for a three-phase approach to blockchain pilot implementation



Taking into consideration lessons learned from existing blockchain consortia, one of the major challenges is setting up a governance framework that properly reflects the incentives needed for participants to collaborate, as well as each participant's obligations. Many different models exist in the marketplace – all with the major target to scale and increase adoption of the blockchain solution(s). The key to a successful consortium is industry- or stakeholder-wide adoption. The consortium needs to be established in such a manner that will entice others to participate. Usually one company or one entity should not have the position to have more power than the rest of the participants.

After each stage, stage gates should be established, in which careful consideration of the go or no-go decision should take place. This can be tied to certain criteria in the realms of technical feasibility, business feasibility or collaboration model. Further blockchain implementation should only move forward if there is support from the involved parties.

In the implementation phase, the goal is to set up the minimum viable product (MVP) and minimum viable ecosystem (MVE) needed for the pilot programme. "Minimum viable" means that the functional scope of the product and number of participants should be reduced to the minimum number, which still provides enough value for the whole ecosystem. In this sense, a MVP encompasses a product, which solves a user pain, but might still be extended and improved in terms of additional functions, interface, user experience and so forth. The MVE is a network of relevant and necessary actors in order to start the pilot. Within the pilot, the MVP is implemented in the MVE.

Implementation includes the definition of functional and technical requirements, the concept design for the solution (i.e. blockchain protocol, network architecture, use of smart contracts), as well as the technical development of the solution. Typically in an agile project approach, the MVP is developed iteratively. Within the development phase, there should be continuous analysis of the MVP, its features and its results, with necessary adjustments to be made accordingly. The decision usually is between conserving (moving on with the current plan) or pivoting (further modify MVP plan to respond to market and user demands). As the solution is ready to launch, the ecosystem needs to be set up by communicating with the stakeholders and orchestrating the relationships

After completion of the MVP and set-up of the MVE, the pilot can go live. This is usually done as a parallel solution to traditional systems and transactions, in order to fully gauge blockchain potential. From this point on, the pilot programme moves to the operation phase and is managed according to the pre-defined plan. The goal of the operation phase is to maintain functionality and provide seamless services.

If the pilot is considered successful by the relevant market participants, further developments might be undertaken. This includes horizontal and vertical extensions, or general scaling of the solution in terms of features or size of the ecosystem. If the decision is made to extend the pilot, relevant stakeholders should be consulted to define goals, a roadmap and governance for leaving the pilot stage.

5. Implications for policy makers

For a successful low-carbon transition enabled by blockchain technology, this report considers three key activities for policy makers as major areas of focus. First, due to the technology's highly influential and disruptive nature in any business model, related stakeholders must be educated and included in a transparent governance approach. Second, in order to ease friction and pave the way for sustainable blockchain development, a number of regulatory issues need to be addressed. Third, a multi-stakeholder collaboration and active co-innovation approach is needed to design feasible pathways for adoption, especially given that blockchain is still a developing technology. Looking into the future, blockchain could also be leveraged as a regulatory tool for monitoring global standards and laws relating to sustainability.

5.1. Support education and research and development

As outlined in the introduction, a lack of knowledge regarding the technology is widely observed in the markets. Raising awareness of the technology's value-adding characteristics, as well as education about its drawbacks due to inefficient designs (e.g. energy consumption for proof-of-work consensus algorithm used in Bitcoin), are essential and need to be broadly understood by decision makers. This could also result in mitigating blockchain designs with high-carbon footprints by actively engaging with industry consortia and the private sector to develop protocols and network designs that are less energy intensive. Observing a variety of DLT technologies (e.g. hashgraphs and tangles) with differing contribution and adverse effects in the low-carbon transition, it will be of essence to develop a strong understanding of the key differences.

It is also important to ensure that careful consideration and analysis are employed in order to assess whether there are clear benefits of deploying a blockchain-based solution rather than utilising existing infrastructures and databases. The OECD has highlighted a number of policy actions to promote technology and innovation, while making sure that digital transformation benefits society. Effective policy actions will seize on opportunities and maximise benefits while addressing challenges and minimising costs. A recent OECD report provides a number of detailed policy actions available to governments in order to facilitate a digital transformation (OECD, 2019a).

- In conjunction with the need for education, **an openly accessible, standardised "toolbox" and education material may be compiled**, aiming to support further research and development in the field. In this way, countries and their private and public research institutions can be supported in developing or building on blockchain solutions. The toolbox can be developed and made available in working groups or by international organisations. Developing the toolbox is not expected to involve high costs, as blockchain technologies are already available and are mostly made accessible by developers under open source licensing.

- **Transferring knowledge to developing economies** will also be key to generate buy-in from related stakeholders, and will be essential to implement the case studies presented in this report. Through research-based collaborations and partnering with public and private organisations, use case concepts and technologies can be jointly validated.

5.2. Take initial steps to improve legal and regulatory environments

Blockchain technology comes with an array of legal and regulatory implications. Due to the nascent status of the technology, legal frameworks and specific laws are yet to be designed and enacted. As a consequence of the physically distributed nature of blockchain networks, sometimes across national borders, the applicable laws and regulations differ for each node (West, 2018). Due to the immutable nature of decentralised registries, and the capability to transfer value by virtue of digital transactions approved by a consensus algorithm, many open questions remain in areas like service level and performance, liability, intellectual property, data privacy, and compliance. The domains of securities law, tax law, legal recognition of data stored on blockchain networks, data privacy laws, and the related improvement of legal and regulatory environments, are discussed due to the proximity of these issues with the previously discussed case studies.

- **In the realm of securities law**, an array of regulatory actions occurred. Various securities and exchange agencies globally have issued statements on their view on blockchain-based token registries (SEC, 2017, Russell, 2017). Yet, the actions are not aligned and treated heterogeneously across different economies. For example, some countries such as China have banned ICOs, whereas they are allowed in countries like Canada, Germany or Israel (Reese, 2018).
- Closely interlinked with the issue introduced above, **tax laws need to be clearly defined in the different jurisdictions**. This is especially relevant for applications in which tokens or coins are issued. For example, for the financing platform described in 3.1, the characterisation of tokens has to be aligned for tax purposes, as there is no global agreement on the legal framework for tokens as described in 1.2. Hence, the platform may be less attractive to users under more stringent regulatory treatment.
- **The path to a frictionless legal recognition of data** stemming from blockchain registries has been advancing. For example, the US state of Tennessee has passed a bill, which recognises that blockchain data and smart contracts have legal effects (De, 2018). Yet, a global coverage of this recognition will be a key success factor for blockchain-based networks.
- Beyond recognising data and its immutable trail on the blockchain, **data privacy regulation is to be considered as well**. With the introduction of the European Union's *General Data Protection Regulation* (GDPR), the question of blockchain technology's compatibility with GDPR arose (Toth, 2018). The "EU Blockchain Observatory and Forum" created a dedicated working group for "blockchain and the GDPR" and launched a report end of 2018 stating that compliance can be achieved by blockchain initiatives but further investigations and rulings are needed (EU Blockchain Observatory and Forum, 2018). **A closer collaboration between governmental regulators and the ecosystem** consisting of actors in the private sectors, such as blockchain consortia and research institutes, needs to be nurtured to cover open questions.

Recently, several communities have formed to drive the exchange and bridging of knowledge gaps between legal practitioners from different jurisdictions and developers (Vidal and Jaramillo, 2017). Moreover, comprehensive legal frameworks on blockchain networks and the data stored therein are being proposed in the market. Nonetheless, the complexity of harmonising jurisdictions is a persisting issue, due to differing approaches in treating the technology. While it is not feasible to strive for global standardisation of legal environments across all jurisdictions, policy makers should work on taking initial steps to clarify regulatory treatment for blockchain adoption. In this regard, adjacent standards might need to be adapted, especially in the realms of consumer protection and banking.

Creating a platform for communities by international organisations, such as the OECD Blockchain Policy Forum and the newly established OECD Blockchain Policy Centre, helps to drive the exchange of information and experiences. The OECD has also recently launched the *Sustainable Infrastructure Policy Initiative* in order to pilot the development of tools, standards, and research, along with the promotion of data to inform decision-making in infrastructure investment and policy. The initiative reaches across many subject areas with technological innovation in infrastructure a key component. The next step would be institutionalisation and formalised working groups bringing key stakeholders together.

5.3. Encourage co-innovation and collaboration

In view of the presented use cases and their proposed positive impact on sustainability and infrastructure investment, it will be key to take a holistic and collaborative approach to developing and adopting blockchain technology. As observed in the market, a multitude of consortia and alliances have already formed across industries and competitors, to jointly shape the underlying technology standards. Interoperability of blockchains across various initiatives will be key to ensuring progress is made.

- A proactive approach is needed to engage with the major alliances of skilled technology firms and players in their respective sectors. Using the existing technology scouting and ecosystem engagement approach, **relevant national and international organisations and NGOs may initiate and govern dedicated working groups** consisting of selected technology providers and industry representatives, working to study the potential benefits of blockchain. The participation of climate-focused organisations in these working groups will be essential. While providing access to required infrastructure and stakeholders, they may convey the necessary knowledge and experience needed to establish measures on a global level and support the timely alignment with regulatory stakeholders. Partners of the working groups can therefore develop concrete approaches to adopting the technology and validate concepts. The working grous need also to ensure careful consideration and analysis in order to assess whether there are clear benefits of deploying a blockchain-based solution rather than utilising existing infrastructures and databases.
- Throughout the development of new blockchain-based approaches, **a significant standardisation effort will be required for globally established networks**. For example, a global infrastructure registry and performance monitoring system will require countries and their regulators to accept common approaches. While moving towards a global standardised system, hybrid standard models may be required. It should be ensured that while countries can decide on their own blockchain standards, these could be aligned on a global level in the future. Careful

consideration and analysis is required in order to assess whether the immense standardisation efforts associated with deploying a blockchain-based solution are worth the benefits rather than using existing infrastructures and databases.

- **Support could include the creation of standards, methodologies, and the sharing of data on infrastructure performance**, including financial and sustainability metrics, by using blockchain-enabled technology platforms that facilitate transparency and stakeholder engagement.
- Beyond closely supporting the prototyping and development of technical systems via the working groups, **governments and relevant national organisations may govern blockchain networks themselves**. In this way, blockchain nodes that span across the participating regulators globally could be governed by a jointly mandated neutral party. Most notably, the use case presented in section 3.4 is designed to be jointly hosted by national regulators globally. Similar to the not-for-profit foundation model leveraged in the realm of ICOs (see sections 1.1 and 3.1), blockchain systems can be governed legally and from a management perspective by organisations mandated by the UNFCCC, or other international organisations.

References

Adhami, S., G. Giudici, and S. Martinazzi (2017), "Why Do Businesses Go Crypto? An Empirical Analysis of Initial Coin Offerings", SSRN: https://ssrn.com/abstract=3046209.

B3i (2018), "B3i Founders form Blockchain Startup", https://b3i.tech/single-news-reader/b3i-incorporation.html.

Badev, A. I., and Chen, M. (2014). "Bitcoin: Technical Background and Data Analysis" Finance and Economics Discussion Series, Division of Research and Statistics and Monetary Affairs, vol. 104, Federal Reserve Board, Washington, D.C.

Bauerle, N. (2018), "What Are Blockchain's Issues and Limitations?", https://www.coindesk.com/information/blockchains-issues-limitations/.

Berke, A. (2017). "How Safe Are Blockchains? It Depends", *Harvard Business Review*, https://hbr.org/2017/03/how-safe-are-Blockchains-it-depends

Betz, R. (2006), "What Is Driving Price Volatility in the EU ETS?", Centre for Energy & Environmental Markets, University of NSW, http://www.ceem.unsw.edu.au/sites/default/files/uploads/publications/PagesfromAETFReviewOctNov06_web-2-1.pdf.

Böhme, R., Christin, N., Edelman, B. & Moore, T. (2015), "Bitcoin: Economics, Technology and Governance", *The Journal of Economic Perspectives*, vol. 29, no. 2.

Bundesministerium für Verkehr und digitale Infrastruktur (2017). "Umsetzung des Stufenplans Digitales Planen und Bauen. Erster Fortschrittsbericht", https://www.bmvi.de/SharedDocs/DE/Publikationen/DG/bim-umsetzung-stufenplan-erster-fortschrittsbe.pdf?__blob=publicationFile.

CLI (2018a), "Navigating Blockchain and Climate Action", Climate Ledger Initiative, December 2018.

CLI (2018b), "Sustainable Land Use", Climate Ledger Initiative, https://climateledger.org/en/Innovation/Use-Cases.33.html.

Conley, J. P. (2017), "Blockchain and the Economics of Crypto-Tokens and Initial Coin Offerings", Vanderbilt University Department of Economics.

Cooper, J. (2018), "Waste Hierarchy: Challenges and Opportunities", https://www.letsrecycle.com/news/latest-news/waste-hierarchy-challenges-and-opportunities/.

De, N. (2018), "Smart Contracts Now Recognized Under Tennessee Law", https://www.coindesk.com/blockchain-bill-becomes-law-tennessee/.

Deloitte (2016), "Navigating a Shifting Landscape Capturing Value in the Evolving Mobility Ecosystem", Deloitte University Press.

Deloitte (2017a), "Blockchain & Cyber Security. Let's Discuss".

Deloitte (2017b), "Blockchain Meets Reinsurance – A Contract Management System Solution", Luxembourg: Inside Magazine EMEA Technology.

Deloitte (2017c), "ICOs – The New IPOs? How to fund innovation in the crypto age".

Deloitte (2017d), "Will Blockchain Transform the Public Sector? Blockchain Basics for Government".

Deloitte (2018a), "IoT Powered by Blockchain. How Blockchains Facilitate the Applications of Digital Twins in IoT".

Deloitte (2018b), "Powered by Blockchain. Reimagining Electrification in Emerging Markets", *Deloitte Insights*, https://www2.deloitte.com/insights/us/en/topics/understanding-blockchain-potential/emerging-markets-electric-grids.html?id=us:2sm:3li:4di4647::6di:20180822174000:&linkId=55872234.

Duran, P. and John, A. (2018), "World Bank Launches World-first Blockchain Bond", https://www.reuters.com/article/us-worldbank-cba-blockchain/world-bank-launches-world-first-blockchain-bond-idUSKCN1L80DP.

EC (2016), "The EU Emissions Trading System (EU ETS)", European Commission, https://ec.europa.eu/clima/sites/clima/files/factsheet_ets_en.pdf.

EC (2018a), "Emissions cap and allowances", European Commission, https://ec.europa.eu/clima/policies/ets/cap_en.

EC (2018b), "Reducing Emissions from the Shipping Sector", European Commission, https://ec.europa.eu/clima/policies/transport/shipping_en.

EDF (2018), "How Cap and Trade Works", Environmental Defense Fund, https://www.edf.org/climate/how-cap-and-trade-works.

European Council (2018), "EU Emissions Trading System Reform: Council Approves New Rules for the Period 2021 to 2030", http://www.consilium.europa.eu/en/press/press-releases/2018/02/27/eu-emissions-trading-system-reform-council-approves-new-rules-for-the-period-2021-to-2030/.

EU Blockchain Observatory and Forum (2018), "Blockchain and GDPR", https://www.eublockchainforum.eu/sites/default/files/reports/20181016_report_gdpr.pdf .

EWF (2018), "Origin", Energy Web Foundation, https://energyweb.org/origin/.

Fiedler, J. and Wendler, A. (2015), "Public Infrastructure Project Planning in Germany: The Case of the BER Airport in Berlin-Brandenburg", Large Infrastructure Projects in Germany. Between Ambition and Realities. Working Paper 3, https://www.hertie-school.org/fileadmin/2_Research/2_Research_directory/Research_projects/Large_infrastructure_projects_in_Germany_Between_ambition_and_realities/3_WP_BER_Flughafen_Berlin_Brandenburg.pdf.

Frankson, S. (2017), "Plastic Bank Deploys a Blockchain to Reduce Ocean Plastic", IBM IT Infrastructure Blog, https://www.ibm.com/blogs/systems/plastic-bank-deploys-blockchain-to-reduce-ocean-plastic/.

G20 (2018), Communiqué, Finance Ministers & Central Bank Governors Meeting, 19-20 March 2018, https://back-g20.argentina.gob.ar/sites/default/files/media/communique_g20.pdf.

GHG Protocol (2018), "Corporate Value Chain (Scope 3) Accounting and Reporting Standard", https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf.

Gilbertson, T. and Reyes, O. (2009), "Carbon Trading. How It Works and Why It Fails", *Critical Currents*, No. 7., Uppsala: Dag Hammarskjöld Foundation.

Glaser, F. (2017), "Pervasive Decentralisation of Digital Infrastructures: A framework for Blockchain Enabled System and Use Case Analysis", Proceedings of the 50th Hawaii International Conference on System Sciences.

Guigon, P. (2016), "10 Practical Steps to Create an Emissions Trading System", World Bank Blogs, https://blogs.worldbank.org/climatechange/10-practical-steps-create-emissions-trading-system.

Insuresilience (2018), "About the Insuresilience Global Partnership", https://www.insuresilience.org/about/.

IPCC (2018), "Organization", http://www.ipcc.ch/organization/organization.shtml.

Jarvis, H. (2018), "Cost of Berlin's BER Airport Now €7.3bn",: https://standbynordic.com/cost-berlins-ber-airport-now-e7-3bn/.

Kachi, A., Unger, C., Böhm, N., Stelmakh, K., Haug, C. and Frerk, M. (2015), "Linking Emissions Trading Systems: A Summary of Current Research", Berlin: International Carbon Action Partnership, https://icapcarbonaction.com/en/?option=com_attach&task=download&id=241.

Mattila, J. and Seppälä, T. (2015), "Blockchains as a Path to a Network of Systems - An Emerging New Trend of the Digital Platforms in Industry and Society", The Research Institute of the Finnish Economy, No. 45.

Microsoft (2017), "Microsoft SharePoint Recognized as a Leader in Gartner Magic Quadrant for Content Services Platforms", https://www.microsoft.com/en-us/microsoft-365/blog/2017/10/10/microsoft-sharepoint-recognized-as-a-leader-in-gartner-magic-quadrant-for-content-services-platforms/.

Miller, R. (2018), "IBM Teams with Maersk on New Blockchain Shipping Solution", https://techcrunch.com/2018/08/09/ibm-teams-with-maersk-on-new-blockchain-shipping-solution/?guccounter=1.

Momtaz, P., Rennertseder, K. & Schröder, H. (2019). "Token Offerings: A Revolution in Corporate Finance?", SSRN: https://ssrn.com/abstract=3346964.

Moseley, M. (2018), "Blockchain, Smart Contracts and Infrastructure", https://www.gihub.org/blog/blockchain-smart-infrabonds/.

Nielsen (2015), "Green Generation: Millennials Say Sustainability Is a Shopping Priority", http://www.nielsen.com/ie/en/insights/news/2015/green-generation-millennials-say-sustainability-is-a-shopping-priority.html.

OECD (2017), "Investing in Climate, Investing in Growth", www.oecd.org/investment/investing-in-climate-investing-in-growth-9789264273528-en.htm.

OECD (2019a), "Going Digital: Shaping Policies, Improving Lives", OECD Publishing, Paris, https://doi.org/10.1787/9789264312012-en.

OECD (2019), "Blockchain at the OECD". https://www.oecd.org/going-digital/blockchain-at-the-oecd.pdf.

Pan, Jianli & Yang, Zhicheng (2018), "Cybersecurity Challenges and Opportunities in the New Edge Computing + IoT World", https://www.researchgate.net/profile/Jianli_Pan/publication/322941089_Cybersecurity_Challenges_and_Opportunities_in_the_New_Edge_Computing_IoT_World/links/5a78e2abaca2722e4df31abb/Cybersecurity-Challenges-and-Opportunities-in-the-New-Edge-Computing-IoT-World.pdf.

Papajak, U. (2017), "Can the Brooklyn Microgrid Project Revolutionise the Energy Market?", https://medium.com/thebeammagazine/can-the-brooklyn-microgrid-project-revolutionise-the-energy-market-ae2c13ec0341.

PTPA (2017), "Good Practice: Accreditation and Verification Approaches under the EU ETS", Partnership on Transparency in the Paris Agreement, https://www.transparency-partnership.net/documents-tools/good-practice-accreditation-and-verification-approaches-under-eu-ets.

Reese, F. (2018), "ICO Regulations by Country", https://www.bitcoinmarketjournal.com/ico-regulations/.

Robertson, R., Marotta, I. and Hogan, I. (2018), "Logistics & Infrastructure: Program Management in the Panama Canal Expansion", PIANC Panama, Panama City, 7-12 May, https://www.conference-service.com/pianc-panama/documents/agenda/data/full_papers/full_paper_346.pdf.

Russell, J. (2017), "First China, Now South Korea Has Banned ICOs", https://techcrunch.com/2017/09/28/south-korea-has-banned-icos/.

SEC (2017), "SEC Issues Investigative Report Concluding DAO Tokens, a Digital Asset, Were Securities, U.S. Securities Laws May Apply to Offers, Sales, and Trading of Interests in Virtual Organizations", U.S. Securities and Exchange Commission, https://www.sec.gov/news/press-release/2017-131.

Steinberger, T., Schwarz, R. and Maznic, S. (2018), "Blockchain: From Disruption to New Business Models", https://www.powerengineeringint.com/articles/2018/05/blockchain-from-disruption-to-new-business-models.html.

Stöcker, C. (2017), "This Isn't Sci-Fi: A Space-Based Sharing Economy Powered by Nano-Satellites Could Save Humanity", World Economic Forum, https://www.weforum.org/agenda/2017/03/sharing-economy-space-blockchain/.

Sümmermann, D., Öge, C.D., Smolenski, M., Fridgen, G., & Rieger, A. (2017), Open Mobility System – OMOS "The Joint Journey Towards Seamless Mobility".

Swan, Melanie (2015), "Blockchain: Blueprint for a New Economy", O'Reilly Media, Inc.

Sweatco.in (2018), "Sweatcoins", https://sweatco.in/.

Token Alliance (2018), "Understanding Digital Tokens: Market Overviews and Proposed Guidelines for Policymakers and Practitioners", https://digitalchamber.org/token-alliance-whitepaper/.

Toth, A. (2018), "Will GDPR Block Blockchain?", World Economic Forum, https://www.weforum.org/agenda/2018/05/will-gdpr-block-blockchain/.

Tran, K. T. and Nguyen, B. L. (2015), "Contract Management for More Effective Development in Vietnam", The World Bank Blog, http://blogs.worldbank.org/governance/contract-management-more-effective-development-vietnam.

Transparency International (2014), "Keep Corruption out to Halt Climate Change", https://www.transparency.org/news/feature/keep_corruption_out_to_halt_climate_change.

UNFCCC (2015), "Paris Agreement", https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

UNFCCC (2018), "International Transaction Log", https://unfccc.int/process/the-kyoto-protocol/registry-systems/international-transaction-log.

Uzsoki, David (2019), "Tokenization of Infrastructure: A Blockchain-based Solution to Financing Sustainable Infrastructure", International Institute for Sustainable Development, Winnipeg.

Vidal, M., John, M. and Rodriguez Jaramillo, A. (2017), "LegalBlock: A Blockchain Legal Community Promoting Collective Wisdom", http://legalblock.co/documents/LegalBlock%20Paper%20I%20.pdf.

Visser, C. & Hanich, Q. (2018), "How Blockchain Is Strengthening Tuna Traceability to Combat Illegal Fishing", http://theconversation.com/how-blockchain-is-strengthening-tuna-traceability-to-combat-illegal-fishing-89965.

West, K. (2018), "Where Is Blockchain?: Jurisdictional Issues That May Affect Distributed Ledgers", https://www.lexology.com/library/detail.aspx?g=35f40e2e-38d8-49d7-81ca-9872d8ab9532.

Wright, A. & De Filippi, P. (2015), "Decentralised Blockchain Technology and the Rise of Lex Cryptographia", SSRN: https://ssrn.com/abstract=2580664.

Financing Climate Futures

RETHINKING INFRASTRUCTURE

Governments recognise that scaling up and shifting financial flows to low-emission and resilient infrastructure investments is critical to deliver on climate and sustainable development goals. Efforts to align financial flows with climate objectives remain incremental and fail to deliver the radical transformation needed. The OECD, UN Environment and the World Bank Group, with the support of the German Ministry of Environment, Nature Conservation and Nuclear Safety, have joined forces under a new initiative – *Financing Climate Futures: Rethinking Infrastructure* – that provides a roadmap to help countries make the transformations in their infrastructure, investment and finance systems that are needed to make financial flows consistent with a pathway towards a low-emission, resilient future.

For more information on *Financing Climate Futures: Rethinking Infrastructure* visit: oe.cd/climate-futures

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Blockchain Technologies as a Digital Enabler for Sustainable Infrastructure

Embracing new technologies that could enable drastic reductions in GHG emissions will be key to delivering low-emissions pathways for growth, but it is not always obvious what the big breakthroughs will look like. This report looks at how blockchain technology can be applied to support sustainable infrastructure investment that is aligned with climate change objectives. It focuses on three key points: the financing of infrastructure initiatives, the creation of visibility and alignment of climate action, and the provisioning of awareness and access for institutions and consumers. Blockchain technology can address these challenges by creating new ways of raising capital, providing transparency through an immutable record of transactions, and establishing new inclusive market mechanisms.

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