Blockchain Potentials and Limitations for Selected Climate Policy Instruments

SEMARNAT
SECRETARÍA DE MEDIO AMBIENTE Y RECURSOS NATURALES

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

CLIMATE LEDGER INITIATIVE

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Blockchain Potentials and Limitations for Selected Climate Policy Instruments,
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List of Acronyms

AI: Artificial Intelligence
AILAC: Independent Association of Latin America and the Caribbean (for its acronym in Spanish)
BNDES: Brazilian Development Bank (for its Portuguese acronym)
BMU: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (for its German acronym)
CLI: Climate Ledger Initiative
CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation
DLT: Distributed Ledger Technology
DRM: Digital Right Management
ETS: Emissions Trading System
EU: European Union
EU ETS: European Union Emissions Trading System
EUR: Euro
GHG: Greenhouse Gas
GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
ICO: Initial Coin Offering:
IKI: International Climate Initiative (for its German acronym)
IoT: Internet of Things
IT: Information Technologies
ITMO: Internationally Transferred Mitigation Outcome
KfW: German Development Bank (Kreditanstalt für Wiederaufbau)
KYC: Know Your Customer (or Client)
MB: Megabyte
MRV: Monitoring (or Measuring), Reporting and Verification
NDC: Nationally Determined Contribution
P2P: Peer-to-Peer
PA: Paris Agreement
PoS: Proof of Stake
PoW: Proof of Work
PV: Photovoltaic
REDD+: Reducing Emissions from Deforestation and Forest Degradation
SDG: Sustainable Development Goals
SEMARNAT: Ministry of the Environment and Natural Resources (for its acronym in Spanish)
SiCEM: Preparation of an Emissions Trading System in Mexico (for its acronym in Spanish)
UN: United Nations
UNFCCC: United Nations Framework Convention on Climate Change
US: United States of America
USD: US Dollar
VAT: Value Added Tax
VMR: Verified Monitoring and Reporting

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Executive Summary

Climate change is one of the major challenges facing humanity. Climate policy instruments must be rapidly implemented to limit global warming well below the 2 degrees Celsius threshold agreed to by over 190 countries in 2015 through the Paris Agreement. The implementation of comprehensive climate policy instruments can be supported by Blockchain technology, a distributed and decentralized way to manage data.

This paper provides an in-depth analysis of the potentials and limitations of Blockchain for particular climate policy instruments.

A Blockchain is a database that is built up incrementally by a network of participating parties. The associated process is subject to the constraints and rules set by the same underlying software the parties run. A Blockchain, as the name suggests, gets built up by blocks of data gradually being "chained" together. A Blockchain database continues to be built and maintained as long as the software continues to be run.

Unlike a centralized database held by a single entity, it continues to run even if individual participants pull out or go bankrupt. It creates an indelible and common record, resistant to tampering by any individual party. Running climate policy instruments on a Blockchain network can eliminate intermediates and thus reduce costs and increase efficiency.

Moreover, Blockchain networks can operate with unique tokens that cannot be copied. Such token may carry unique information associated to goods or services and related to a specific time period. While image files, for example, can be copied and it is impossible to say which of the copies is "the original asset," a token on the Blockchain cannot be multiplied. In the climate context, such Blockchain-based token may be used to represent emission allowances, Monitoring (or Measuring), Reporting and Verification (MRV) data or results-based climate finance. This makes the technology especially relevant for climate policies that operate across jurisdictions.

However, such systems also come with considerable limitations. Challenges related to lower transaction management, network governance, energy consumption, limited scalability and the lack of maturity and proven experience could reduce the overall suitability of Blockchain approaches for climate policy instruments.

Given the potentials and limitations of current Blockchain networks, this paper suggests pursuing a Blockchain approach for climate policy instruments only when other conventional approaches have failed to deliver the expected benefits, or if a Blockchain can offer higher quality benefits at comparable or lower cost.

To examine the potential and usability of a Blockchain for climate policy, the study includes a decision tree to evaluate the usability of four Blockchain platforms. The decision tree introduces a checklist against which climate policy instruments (and their infrastructure needs) can be examined. In a subsequent step, the usability of selected Blockchain platforms is evaluated based on criteria such as programmability, operating costs and security. The evaluation concludes that the Ethereum and Hyperledger Blockchain platforms currently appear to be the most suitable for implementing climate policy applications.

The study also examines the overall potential for a Blockchain application in the context of three specific climate instruments: an Emissions Trading System (ETS), MRV systems for mitigation actions and a tracking system for climate finance.

A Blockchain may indeed facilitate ETS implementation by allowing such systems to apply a wider scope beyond heavy industry. In addition, a Blockchain application can improve the distribution of allowances – for example, by ensuring transparent auctioning of allowances. The potential for a Blockchain application is especially strong in situations with international dimensions, such as ETS linking between jurisdictions or the avoidance of double counting of greenhouse gas (GHG) allowances or offsets. In that context, the study examines the option of running an Emissions Transaction Registry on a Blockchain network. Analyzing the pros and cons of a centralized and a decentralized registry system reveals strengths and weaknesses inherent to both types of systems. A centralized managed registry is well in line with governmental ETS core tasks, such as the allocation of allowances and the management/supervision of registry accounts. Regarding the data transaction itself (allowances, offset units or verified emissions), it is the tokenization of units within an ETS that promises new and enhanced capabilities, including the avoidance of double counting and increased interoperability.

With respect to MRV systems for mitigation actions, the study finds that many of the identified MRV challenges may be addressed through a Blockchain approach. Coupling the benefits of a decentralized database with smart contract applications and Internet of Things (IoT) can help automate entire MRV processes, thus lowering transaction costs and reducing complexity. Many MRV systems for GHG emissions work on separate streams (public and private), generating centralized data silos and preventing the exchange of data. Sharing MRV data in decentralized networks could trigger interactions between existing MRV systems, thereby increasing efficiencies and improving overall data quality.

MRV systems for climate finance can also benefit from the advantages of a Blockchain. Blockchain-based solutions could provide transparency and security to climate finance initiatives. Blockchain networks enable the tracing of climate finance so that all participants of a given project can follow, almost in real time, the financial flows from donor to recipient via a universal ledger. Moreover, the possibility to create entire token economies (e.g., through incentives) on Blockchain networks make the technology highly relevant for results-based climate finance.

However, the decision to apply a Blockchain approach for a specific climate policy instrument should be based on a thorough evaluation. The unique characteristics of decentralized network architectures currently come with downsides, such as slow transaction management and limited governance options. Building a climate instrument on a decentralized and distributed Blockchain network must balance the applicable pros and cons against conventional and centralized approaches. Nevertheless, the identified potential of Blockchain applications for climate policies is promising and could indeed contribute to the accelerated implementation of international climate policy instruments that help achieve the Paris Agreement's long-term temperature goal.

Resumen Ejecutivo

El cambio climático es uno de los mayores desafíos que enfrenta la humanidad. Los instrumentos de política climática deben ser implementados rápidamente para limitar el calentamiento global muy por debajo del umbral de los 2 grados centígrados acordado por más de 190 países en 2015 a través del Acuerdo de París. La implementación de instrumentos integrales de política climática puede ser apoyada por la tecnología de Blockchain, una manera distribuida y descentralizada de administrar datos.

Este documento proporciona un análisis a fondo de los potenciales y las limitaciones del Blockchain para instrumentos de política climática particulares.

Un Blockchain es una base de datos que se construye de forma incremental por una red de partes participantes. El proceso asociado es sujeto a las restricciones y reglas establecidas por el mismo software subyacente que ejecutan las partes. Un Blockchain, como el nombre en inglés sugiere, se acumula mediante bloques de datos que se "encadenan" gradualmente. Una base de datos Blockchain se sigue construyendo y manteniendo mientras el software continúa ejecutándose.

A diferencia de una base de datos centralizada retenida por una sola entidad, continúa funcionando incluso si los participantes se retiran o van a bancarrota. Crea un registro indeleble y común, resistente a la manipulación por cualquier participante. La ejecución de instrumentos de política climática en una red de Blockchain puede eliminar intermedios y, por lo tanto, reducir costos y aumentar la eficiencia.

Además, las redes de Blockchain pueden operar con tokens únicos que no pueden copiarse. Dicho token puede llevar información única asociada a bienes o servicios y relacionada con un periodo de tiempo específico. Mientras que los archivos de imagen, por ejemplo, se pueden copiar y es imposible decir cuál de las copias es "el activo original", un token en el Blockchain no se puede multiplicar. En el contexto climático, este token basado en Blockchain se puede utilizar para presentar los permisos de emisión, los datos de Monitoreo (o Medición), Reporte y Verificación (MRV) o financiamiento climático basado en resultados. Esto hace que la tecnología sea especialmente relevante para las políticas climáticas que operan en todas las jurisdicciones.

Sin embargo, tales sistemas vienen con limitaciones considerables. Los desafíos relacionados con una menor administración de las transacciones, la gobernanza de red, el consumo de energía, la escalabilidad limitada, y la falta de madurez y experiencia demostrada podrían reducir la idoneidad general de los enfoques de Blockchain para los instrumentos de políticas climáticas.

Dados los potenciales y las limitaciones de las redes de Blockchain actuales, este documento sugiere buscar un enfoque de Blockchain para los instrumentos de política climática solo cuando otros enfoques convencionales no han brindado los beneficios esperados, o si un Blockchain puede ofrecer beneficios de mayor calidad a un costo comparable o menor.

Para examinar el potencial y la usabilidad de un Blockchain para política climática, el estudio incluye un árbol de decisión para evaluar la usabilidad de cuatro plataformas de Blockchain. El árbol de decisión introduce una lista de verificación contra la cual los instrumentos de política climática (y sus necesidades de infraestructura) pueden ser examinados. En un siguiente paso, la usabilidad de las plataformas de Blockchain seleccionadas se evalúan en base a criterios tales como la capacidad de programación, los costos operativos y la seguridad. La evaluación concluye que actualmente las plataformas de Blockchain Ethereum e Hyperledger parecen ser las más adecuadas para implementar aplicaciones de políticas climáticas.

El estudio también examina el potencial general para la aplicación de un Blockchain en el contexto de tres instrumentos climáticos específicos: un Sistema de Comercio de Emisiones (SCE), sistemas de MRV para acciones de mitigación y un sistema de rastreo para el financiamiento climático.

En efecto, un Blockchain puede facilitar la implementación de un SCE al permitir que dichos sistemas apliquen un mayor alcance que vaya más allá de la industria pesada. Además, el uso de un Blockchain puede mejorar la distribución de derechos de emisión, por ejemplo, al asegurar una subasta transparente de derechos de emisión. El potencial para el uso de un Blockchain es especialmente fuerte en situaciones con dimensiones internacionales, como el enlace de SCE entre jurisdicciones o al evitar el doble conteo de los permisos de emisión o de compensaciones de gases de efecto invernadero (GEI).

En ese sentido, el estudio examina la opción de ejecutar un Registro de Transacción de Emisiones en una red de Blockchain. El análisis de las ventajas y desventajas de un sistema de un registro centralizado y uno descentralizado revela las fortalezas y debilidades relacionadas a ambos tipos de sistemas. Un registro administrado centralizado está alineado con las tareas centrales gubernamentales de SCE, tales como la asignación de permisos de emisión y la administración/supervisión de las cuentas de registro. Con respecto a la transacción de datos en sí (permisos de emisión, unidades de compensación o emisiones verificadas), es la tokenización de las unidades dentro de un SCE la que promete capacidades nuevas y mejoradas, incluidas la prevención de doble conteo y una mayor interoperabilidad.

Con respecto a los sistemas de MRV para acciones de mitigación, el estudio encuentra que muchos de los desafíos de MRV identificados pueden abordarse a través de un enfoque Blockchain. Conectando los beneficios de una base de datos descentralizada con aplicaciones de contratos inteligentes y el Internet de las Cosas (IoT, por sus siglas en inglés) pueden ayudar a automatizar los procesos completos de MRV, reduciendo costos de transacción y la complejidad. Muchos sistemas de MRV para emisiones de GEI funcionan en flujos separados (públicos y privados) generando silos de datos centralizados y evitando el intercambio de datos. Compartir los datos de MRV en redes descentralizadas podría desencadenar interacciones entre los sistemas de MRV existentes, aumentando así la eficiencia y mejorando la calidad general de los datos.

Los sistemas de MRV para el financiamiento climático también pueden beneficiarse de las ventajas de un Blockchain. Las soluciones basadas en Blockchain podrían proporcionar transparencia y seguridad a las iniciativas de financiamiento climático. Las redes de Blockchain permiten rastrear el financiamiento climático para que todos los participantes de un proyecto determinado puedan seguir, casi en tiempo real, los flujos financieros del donante al receptor a través de un libro de contabilidad universal. Además, la posibilidad de crear economías de token completas (por ejemplo, a través de incentivos) en redes Blockchain hace que la tecnología sea altamente relevante para el financiamiento climático basado en resultados.

No obstante, la decisión de aplicar un enfoque Blockchain para un instrumento específico de política climática debe basarse en una evaluación exhaustiva. Las características únicas de las arquitecturas de red descentralizadas actualmente tienen desventajas, como la administración lenta de transacciones y las opciones de gobernanza limitadas. La construcción de un instrumento climático en una red Blockchain descentralizada y distribuida debe equilibrar los pros y los contras aplicables con los enfoques convencionales y centralizados. A pesar de ello, el potencial identificado del uso de Blockchain para políticas climáticas es prometedor y, de hecho, podría contribuir a implementación acelerada de instrumentos de política climática internacional que ayudan a alcanzar la meta de temperatura a largo plazo del Acuerdo de París.

1

Introduction

1. Introduction

Blockchain, the technology behind Bitcoin, has triggered burgeoning interest as an innovative tool to achieve Sustainable Development Goals (SDG). The energy sector and certification in supply chains have spearheaded the surge in new ideas and pilot projects using Blockchain technology for sustainable development. Discussions on how Blockchain could be applied in climate policy only recently started.

The concept of Blockchain as a decentralized encrypted currency was first described in 2008 in a cryptography blog by a person or a group of persons named "Satoshi Nakamoto" (NAKAMOTO 2008). In the wake of the global financial crisis, Nakamoto found a way to enable the direct transfer of online payments from sender to recipient without an intermediary. The trust-building technology (i.e., cryptographic approach) behind it soon became seen as the actual revolutionary aspect of a Blockchain.

The decentralized and trust-building character of Blockchain technology recently sparked interest within the climate community. In 2017 the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) published an article on "How Blockchain Could Boost Climate Action" (UNFCCC June 1, 2017)[(1)]. The article highlighted potentials for Blockchain applications in the areas of emissions trading, clean energy trading, climate finance and tracking of greenhouse gas (GHG) emissions.

The Secretariat's view on Blockchain in the context of climate action is shared by many countries[(2)]. In September 2018 the Registry System Administrators under the UNFCCC Kyoto Protocol established a working group to assess whether Blockchain is an adequate technology to ensure accurate, secure and efficient transfer of GHG units between registry systems in the future[(3)].

To contribute to the ongoing discussions on Blockchain and climate, this briefing paper provides an overview of the opportunities and challenges for applying Blockchain solutions to key areas of today's climate economics: emissions trading, the tracking of climate mitigation efforts and climate finance flows.

These areas are also key elements of the 2015 Paris Agreement on climate change with corresponding provisions on

- emissions trading (e.g., transferable mitigation outcomes) in Article 6;
- the tracking of mitigation efforts in Articles 4 and 13 (e.g., enhanced transparency framework); and
- guidance on climate finance flows in Articles 9 and 13.

The objective of this paper is to inform national policymakers as well as the international climate community about the application potential of the Blockchain technology for the abovementioned key policy areas.

This paper addresses the key features and possibilities of different platforms that support Blockchain technology and how they can be used for solving some of the most prominent issues related to climate change instruments (e.g., transparency, efficiency, data tampering, trustability).

The report then analyzes the challenges of selected climate instruments (i.e., an Emissions Trading Registry for transactions, MRV systems for mitigation actions and a tracking system for climate finance) and examines how Blockchain could help address these challenges.

(1) See https://unfccc.int/news/how-blockchain-technology-could-boost-climate-action

(2) The interest in the technology was expressed through submissions by various countries, including Mexico, Switzerland and Norway. Furthermore, exploring Blockchain's potential was called for by Costa Rica on behalf of the Independent Association of Latin America and the Caribbean (AILAC) group of countries and by Ethiopia on behalf of the African Group; see www.unfccc.int for further references.

(3) See report of the administrator of the international transaction log under the Kyoto Protocol from 10/2018, FCCC/SBI/2018/INF.10

It also highlights the primary challenges of Blockchain itself, including lack of maturity, the difficulty of finding programmers in developing countries, costs, the inability to adapt the tool once in use, among others. Despite these shortcomings, the paper finds Blockchain to be a viable option for some of the analyzed climate instruments, while an undesirable one for others.

Through practical exercises, the paper allows readers to answer key questions and complete a decision tree to help determine whether Blockchain is a suitable option or if another digital solution would be preferable. This valuable methodology can be applied to distinct climate instruments in different countries.

In the paper "Blockchain on Mexican Climate Instruments: Emissions Trading and MRV systems" (GIZ, 2018), the suitability of Blockchain is evaluated for these same climate instruments in the context of Mexico, with additional recommendations from the institutional, legal and technical points of view.

2

Blockchain

A Distributed and Decentralized Ledger Technology

2. Blockchain – A Distributed and Decentralized Ledger Technology

A ledger is nothing but a database containing information. Usually ledgers are centralized and thus managed by one single authority. The authority decides what will be stored or amended in the ledger. Governments that provide passports to their citizens or banks that confirm the financial state of their clients all operate with centralized ledger systems. Centralized ledger systems are fast and efficient. There is only a limited risk that different realities or mutual exclusive data entries occur since changes to the ledgers are done by one single authority (e.g., governments or banks). Such authorities work along pre-defined rules (laws/regulations or contractual provisions/general terms and conditions) when updating their systems.

The great disadvantage of centralized ledger systems is that their users need to trust this authority. Moreover, such authority can be costly and sometimes even difficult to find.

Data that is processed via a distributed ledger system is not managed by one single authority but by a community of participants. Ensuring a unified status of a distributed ledger can prove cumbersome in cases where a group of individuals work on one and the same set of data (e.g., via Word or Google Docs).

Decentralizing the management of a distributed ledger system avoids misunderstandings when updating information in distributed databases. Here, the corresponding ledger cannot be simply updated by its users. Any update must follow a specific set of rules. The best-known decentralized ledger system is a Blockchain network.

The participants of a Blockchain network update "their" database by regularly voting on what happened (e.g., transactions of any kind) within the community. Once the majority of participants has agreed on one set of information (consensus), the new data is assembled into an information block that is cryptographically chained to the previous block. Every participant stores the agreed information block on its server before the process starts again. At the end, all network participants have the same chain of information blocks on their server. This makes it impossible for a single participant to launch fraudulent activities by, for example, changing past ledger entries. Moreover, one participant cannot simply take away a digital asset (e.g., an ownership title stored in the ledger) from another participant. It is remarkable that a Blockchain provides these features without the need for a trusted third party.

3

Blockchain

Technical Fundamentals

3. Blockchain – Technical Fundamentals

Blockchain is a database that is built up incrementally by a network of participating parties. The associated process is subject to the constraints and rules set by the same underlying software they run.

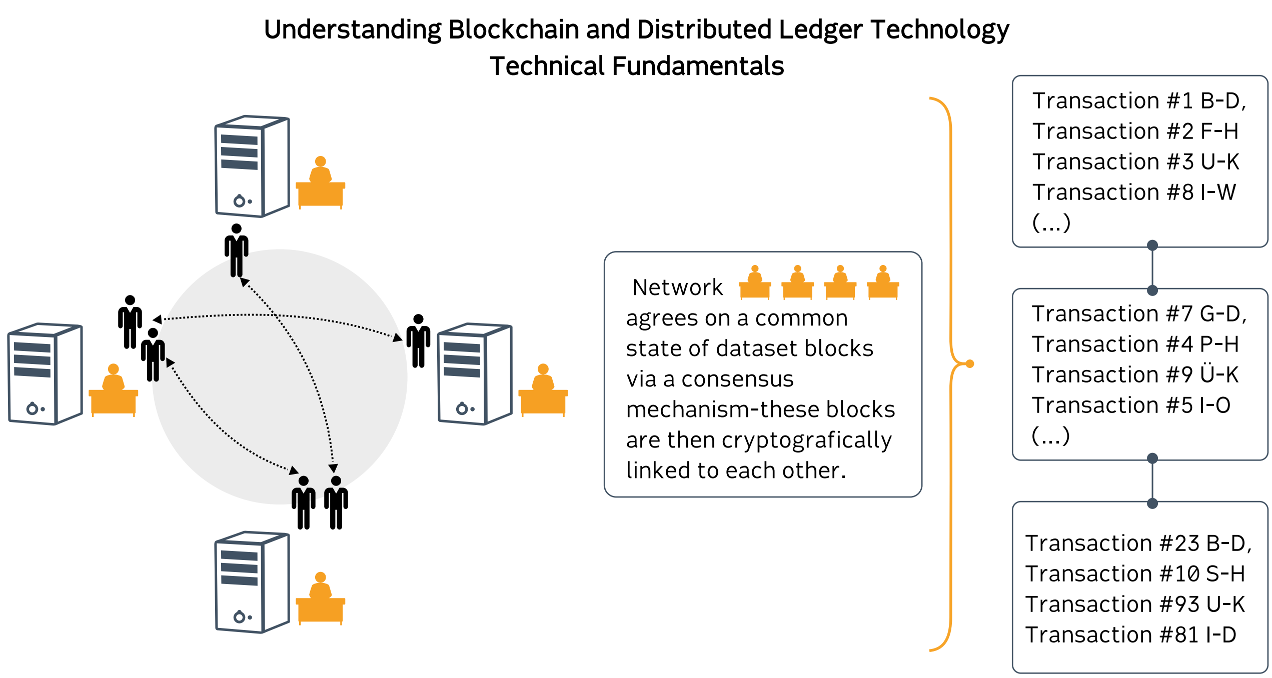
A Blockchain, as the name suggests, gets built up by blocks of data gradually being "chained" together. A Blockchain database continues to be built and maintained so long as the software continues to be run. Thus, unlike a centralized database held by a single entity, it continues to run even if individual participants pull out or go bankrupt. It creates an indelible record, resistant to tampering by any individual party.

3.1 Benefits of a Distributed and Decentralized Network

The infrastructure of a Blockchain network consists of distributed computer servers (called nodes, validators, miners, etc.). These servers operate under the rule that interactions are only made by servers permanently following rules of the protocols. Intermediaries (e.g., banks, clearing houses, trading platforms, centralized service providers, etc.) are hence no longer needed.

The decentralized character of Blockchain technology is ensured by a respective consensus protocol and provides new possibilities (e.g., for the energy market) by facilitating the direct exchange between decentralized energy producers and consumers. Complete transparency across all transactions gives stakeholders within such networks the confidence to securely conduct transactions, even with anonymous partners.

Figure 1. Blockchain network, its participants and transaction management



Source: Author's own work.

3.2 Why Blockchain Beats Out a Shared Database: Data Management and Tokenization

The growing amount of data gathered by devices and automated processes will increasingly require management using specific algorithms that evaluate the data and draw conclusions and even projections out of it. It is important to ensure that this data is accessible to not just one but many parties. The right to gather and interpret specific data should be reflected in future infrastructures to help limit the power and influence of centralistic and monopolistic data corporations. Shared databases are run by centralized companies where at one point a central Information Technologies (IT) administrator can execute full read and write access rights. In Blockchain networks, on the other hand, there is no central administrator. In fact, Blockchain technology allows users to share data while retaining control. This in turn fosters transparency, greater stakeholder inclusion and distributed data management.

Blockchain technology allows users to share data while retaining control. This in turn fosters transparency, greater stakeholder inclusion and distributed data management.

Tokenization can provide an important means for keeping Blockchain networks decentralized. In the underlying context, a token can be understood as a digital asset that is stored on the Blockchain. This digital asset can be anything somehow tied to a real-world value.

The important feature of such a Blockchain-based token/digital asset is that it cannot be copied. While image files, for example, can be copied and it is impossible to say which of the copies would be "the original asset," digital assets on the Blockchain (e.g., tokens) cannot be multiplied. While it can be said that an image file is an "asset" only if one has the right to use it, this right is abstract from the digital realm. For an image, the ownership or right to use exists independent of who else has a copy. This is not the case for Blockchain-based tokens. The ability to use a token on a Blockchain is digitally restricted as direct expression of right to use. Digital Rights Management (DRM) is an attempt to restrict the use of copyrighted material. But the technical requirements of DRM are very different from how Blockchains work. DRM is traditional in the way that it tries to restrict copying. Blockchains copy everything to everyone and create scarcity by not withholding the actual payload (DIEDRICH 2016). That is the reason why a Blockchain-based token has acquired a meaning that is tied to scarcity. Such scarcity is not possible on a shared database with a central IT administrator.

Tokens may be generated based on protocol rules representing valuable information. By monetizing the latter, the Blockchain network

a. can be maintained and/or

b. incentivize (and remunerate) envisaged behaviors (e.g., data gathering).

Tokenization allows for assembling unique information, associated to goods or services and related to a specific time period.

But how can a Blockchain-based token be monetized? Tokenization allows for assembling unique information, associated to goods or services and related to a specific time period. People or whole communities involved in supply chains are able to add objective (or independent) information to the life cycles of goods and services. The fisherman in Peru, the farmer in Kenya, the woodcutter in Romania or the tourist guide in Indonesia could all put information related to their activities on decentralized ledgers via smart phones that would allow to have broader information on the associated impacts from goods and services in their region. In return for payment, smart contracts (discussed below) would offer access to this tokenized data to interested stakeholders, which would be directly forwarded via microtransactions to the data collectors. Data would not only be valuable for governments and multi-lateral organizations but also for food companies, insurers or impact investors.

3.3 Smart Contracts

Blockchain technology enables networks to work on an agreed set of transaction histories, and it is also possible to associate these transactions with conditions (which are also shared by the network): If transaction A has occurred, transaction B is automatically executed (principle of "smart contracts"). Smart contracts are complementary mechanisms within Blockchain networks that allow, for example, for the automatic coordination of decentralized suppliers and buyers or the automatic allocation of pricing tags to environmental attributes.

If the code of a smart contract is displayed transparently on a Blockchain, embedded on various distributed ledgers so every network participant can anticipate the outcome of the smart contract functions, a smart contract may soon be able to function as an independent, verifiable "middleman."

If the code of a smart contract is displayed transparently on a Blockchain, embedded on various distributed ledgers so every network participant can anticipate the outcome of the smart contract functions, a smart contract may soon be able to function as an independent, verifiable "middleman."

Smart contracts do not need Blockchains to work. In fact, smart contracts are nothing but coded conditions that execute certain functions based on pre-defined events. However, smart contracts complement the advantages of the Blockchain technology. They can be summarized by the term "multi-lateral interoperability," which encompasses multi-cast communication,[(4)] immutability, real-time tracking of transactions and faster processing of payment transactions.

3.4 Data Immutability

Blockchain databases are considered to be immutable, not only because the individual information blocks are encrypted and distributed on many computers, but also because transactions can be viewed and checked by all participants involved, as the transaction history is literally copied on numerous computers in the network. A participant that, for whatever reason, might want to change the entrance of a specific transaction would have to access every computer in the network, which is theoretically possible but economically unfeasible. The distributed character of Blockchain technology provides such networks with a new level of data security.

Transactions can be viewed and checked by all participants involved, as the transaction history is literally copied on numerous computers in the network.

Unlike normal distributed databases, Blockchains use consensus mechanisms that enable the updating of data through cryptography and distributed consensus algorithms. These consensus algorithms ensure that the data of the network is the same for all participants, which is crucial for legitimizing data entries. Consensus mechanisms enable decentralized governance of a Blockchain network.

(4) See report of the administrator of the international transaction log under the Kyoto Protocol from 10/2018, FCCC/SBI/2018/INF.10

A transaction in a Blockchain network is determined by its participants as correct and should be ticked off. If most of the network participants consider the transaction to be correct (by applying a consensus mechanism), the transaction, together with a series of other transactions, is built into a block. This block is cryptographically linked (chained) to the previous block, which is also composed of a set of previous transactions.

The way the blocks are linked with each other involves so-called "hash" functions and ensures that every block is linked to the previous one.

How do hashes work?

A hash is something like the unique digital fingerprint of any imaginable set of data, regardless of its size. Technically, a hash is comparable to a cross sum. A hash formula, however, is much more complex than just adding numbers for a cross sum – a hash can be thought of a cross sum mixer that factors, adds and multiplies every single digit (including letters) of a dataset and calculates a certain result from it: the hash.

As with cross sums, a hash can be much shorter than the original hashed text (data). It is also impossible to conclude from the hash back to the initial dataset – and that is a feature! For example, the hash of the phrase "nothing is decided until everything is decided" always has the hash:

9f62f85d500c8d4682c2aa9f8a00d89658be956b3a680dfd370eb1c9bb94e445.

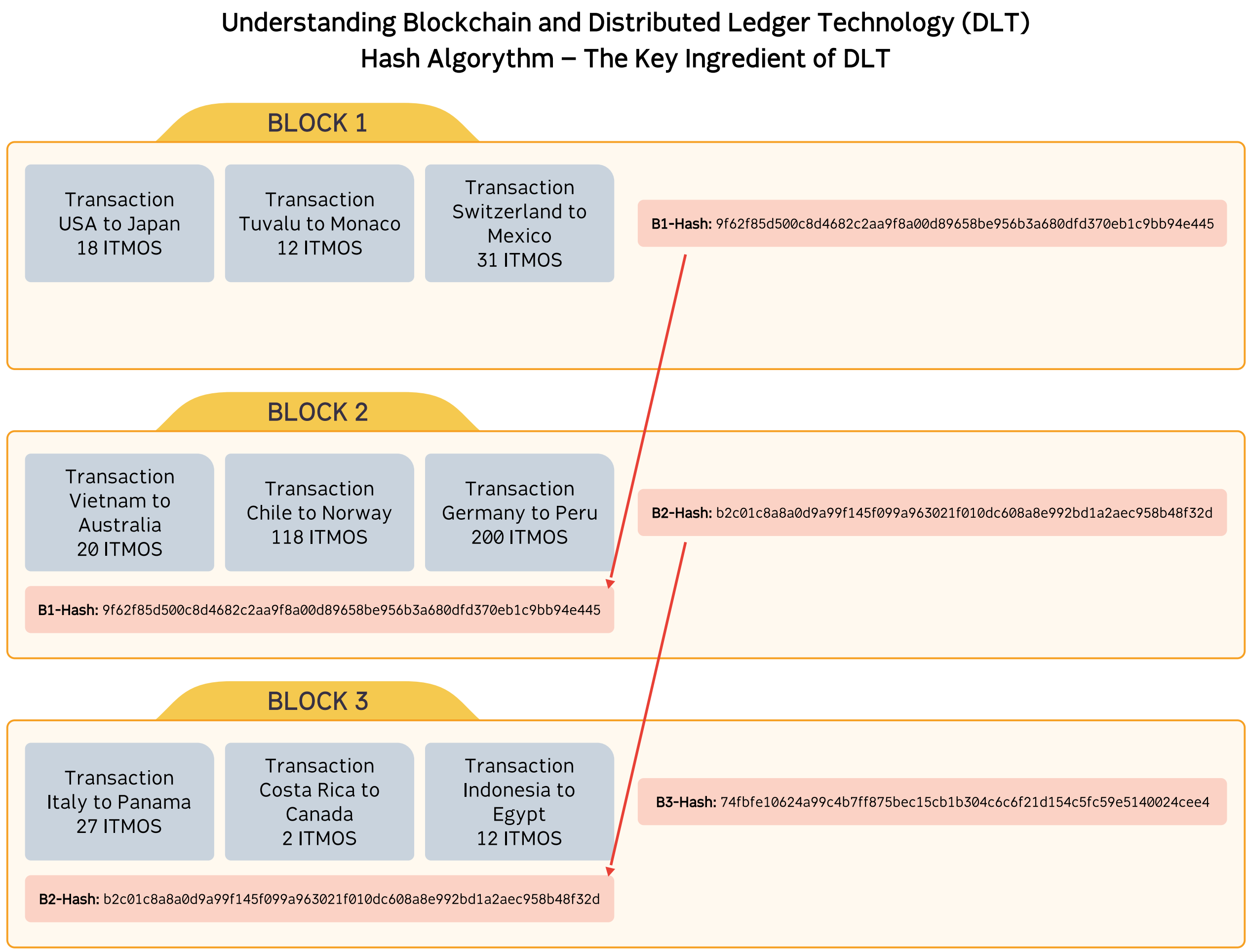
A change of just one minor part of the dataset causes the so-called "avalanche effect" in the "hash mixer" and leads to a completely different hash. For example, the slightly altered phrase "nothing is decided until everything's decided" has the hash:

3f9801bc00d0a466b42c006dbbbf312ce38d1cf515a999bb09f9b556feeb56244.

To illustrate the practical relevance of hashes, a Blockchain network for cooperative approaches, run and maintained by participating countries to the Paris Agreement (PA) – the "PA Network" – is assumed. In Figure 2 below, the United States of America (US) and Japan agree on a transaction of 18 Internationally Transferred Mitigation Outcomes (ITMOs). Similarly, Tuvalu and Monaco agree on a transaction of 12 ITMOs, and Switzerland and Mexico on 31 ITMOs. These three ITMO transactions are added to BLOCK 1. One block consists, then, in three countries sending and three countries receiving ITMOs.

These transactions are broadcasted to the network and recorded by all countries that participate in the PA Network – even by those countries that are not involved in the specific transaction of BLOCK 1. Every transaction will be stored into a block together with other transactions. Once the block is "full," all the transaction data inside will be turned into a unique combination of 64 digits, a block hash (B1-Hash) in the figure. Later on, Vietnam, Chile and Germany send mitigation outcomes to Australia, Norway and Peru, respectively. These transactions will be added to the B1-Hash and turned into a new hash, named B2-Hash. This new hash, in turn, will be added to the next set of transactions and so on and so forth.

Figure 2. Cryptographically chained blocks with transactions of mitigation outcomes



Source: Climate Ledger Initiative, 2018a.

The respective block hashes are central for the immutability, safety and low costs of the overall network. The last block hash of the PA Network will always contain the history of all ITMO transactions.

The greatest challenge of current distributed databases remains synchronizing data around the globe in such a way that every participant looks at the same set of data. In the assumed PA Network, all Parties would continuously check and verify all transactions within the network and then only compare their last block hashes with the last block hashes of the other participants (i.e., Parties/countries) (Climate Ledger Initiative, 2018a).

3.5 Decentralization and Cryptography

One core benefit of Blockchain is the element of decentralization that makes them **highly secure** and more resilient against accidental failures (there is no single point of failure/attack). Data remains reliably available even if a large portion of the network is offline.

One core benefit of Blockchain is the element of decentralization that makes them highly secure and more resilient against accidental failures (there is no single point of failure/attack).

Blockchains allow anyone to send assets (via respective tokens) to anyone without having to rely on an intermediary. **Decentralization** is provided by a consensus mechanism, which relies solely on the machines connected by the network running the same piece of software, regardless of who their owners are. This in return provides for built-in trust of the network since it allows for transaction between unknown participants.

Cryptography adds a high level of **security** to Blockchains. Unlike traditional accounting systems, Blockchain is based on the concept of triple-entry accounting in which the time variable is inserted and attached to all transactions so that they are located and sorted in a specific order. This temporality – for example, the fact that each transaction is cryptographically coded and "stamped" with date and time – allows for the tracking of all "blocks of the chain."

Finally, Blockchain-based operations like transaction recording are fully **automated**, thereby decreasing the risks of manual accounting errors. The network automatically validates new transactions at the same time. Everyone connected to it can audit the entire process, which ensures that incorrect data is rejected and proper information is propagated.

Figure 3. Key features of combining decentralization and cryptography

Decentralization and cryptography in DLT provide for the following Key features:

Shared "Publicly"	Decentralized	Secure	Trusted	Automated
Servers, or nodes, maintain the entries (blocks) and every node sees the transaction data in the blocks when created.	There is no central authority required to approve transactions and set rules – the Blockchain-based workflow is decentralized.	The database is an immutable record. Posts to the ledgers cannot be revised or tampered with – not even by the operators of the database.	Distributed nature of the network requires computer servers to reach a consensus, which allows for transactions to occur between unknown network participants.	The software which enables Blockchain-based operations prevents the entry of conflicting or double transactions into the data set. Transactions occur automatically.

Source: Author's own work.

3.6 Governance: Permission-Less and Permissioned Blockchains

The distributed and cryptographic character of Blockchain makes it possible to **publicly share** entries to the ledgers. However, access to perform certain tasks on the Blockchain, such as data entries, can be limited, depending on protocol rules and permissions.

Permission can be required in a way that

- allows to only read the information on the Blockchain;
- limits the parties who can transact on the Blockchain; and
- sets who can serve the network by writing new blocks into the chain.

Permission-less Blockchain networks are open to everyone. The transaction logs of, for example, Bitcoin and Ethereum are accessible to anyone online. Anyone may become a ledger node (i.e., hold a copy of the ledger) and add valid data entries. All participants can freely enter or leave the network at any time, without identifying or authenticating themselves. Anyone can read the chain, make legitimate changes and write a new block into the chain (if they follow the rules). The permission-less feature makes Blockchains like Bitcoin very decentralized and "censor-proof."

While decentralized Blockchains like peer-to-peer **(P2P) market** places (e.g., sharing economy, energy trading) are highly efficient, decentralized Blockchain networks also have their downsides. Permission-less Blockchain-based databases are often **slower** than permissioned Blockchains. Depending on the level of decentralization, operations on Blockchain networks perform a **lower transaction** management, which eventually could create **higher costs** compared to conventional databases. The cost issue is not exclusively linked to the applied consensus mechanism but may also occur as a consequence of parallelization. Writing into a centralized database needs to be done once, while writing into a distributed ledger needs to be done as many times as there are nodes that carry a copy of the ledger (BORN 2018).

In contrast to **permission-less Blockchains**, a permissioned Blockchain network (e.g., Hyperledger) relies on a consensus mechanism controlled by a **group of known participants** or a **single participant** (e.g., a company or government agency), which adds some degree of centralization. Only authorized entities can hold a copy of the ledger or participate in transactions. In a permissioned Blockchain, the nodes know each other at least to a certain degree.

Permissioned Blockchains can process transactions much faster without compromising network security. The sacrifice of decentralization in favor of security and scalability is particularly attractive to networks with pre-defined stakeholders acting within specific boundaries. It leverages the technology's cryptographic features and still ensures scalability to meet the needs of high transaction throughputs.

Popular examples of permissioned Blockchains include R3 Corda[5] and Quorum,[6] two platforms designed for the financial service industry. R3 Corda includes different access levels for different node categories, according to the organizational roles and responsibilities. Quorum is a private version of Ethereum and moves parts of its transaction data off-chain but stores the cryptographic hashes of transaction data on-chain.

In the end, the difference between permissioned and permission-less Blockchains is based on the decision of *who* should participate in the consensus process: Should it be every network participant or just permissioned participants?

A centralized database can always be programmed like a Blockchain and behave as such. However, by choosing Blockchain technology, by design, it is the decentralization that is acquired and that provides the above-mentioned security aspects that in a centralized system would have to be developed and maintained by a central administrator. Should Blockchain consensus protocols continue to perform securely, permissioned systems may eventually disappear as their redundancy becomes apparent. Decentralization strengthens the resilience of Blockchain networks. Their stability increases with the amount of network participants. Permissioned Blockchains explicitly trust selected nodes to manage the networks participants. These selected nodes will sooner or later reach performance limits, which will slow down decentralization and thus permissioned networks' resilience.

(5) See https://www.r3.com
(6) See https://www.jpmorgan.com/global/Quorum

To blend the benefits of both options, hybrid forms of permissioned and permission-less Blockchains have gained prominence, especially in the context of government applications of Blockchain.

The permissioned entry to a Blockchain is required in cases where activities should be associated with a specific legal identity. Most jurisdictions have financial provisions in place to avoid money laundering and other white-collar crimes. These provisions require any Blockchain network with links to financial markets to have a permission layer in place to identify the actors in their network.

3.7 Key Challenges of Blockchains

The decentralized and distributed character of Blockchain networks leads to challenges that could put the overall suitability of a Blockchain approach at risk. The key challenges of today's Blockchain networks are summarized in the table below.

Table 1. Key challenges of Blockchain networks

Challenge/Barrier	Description	Solution
Energy consumption	The Proof of Work consensus mechanism in permission-less Blockchains (Bitcoin, Ethereum) leads to high energy consumption.	Alternative ways of finding consensus already exist (i.e., Proof of Stake).
Scalability	Permission-less Blockchains are currently not able to scale up their performance capacities due to their inefficient consensus protocols.	Scalability is a far smaller issue within permissioned Blockchains. Other ways to improve scalability involve off-chain transactions or second layer solutions.
Lack of maturity and proven experience	Companies introducing Blockchain to decentralize certain economic relationships do not have the means to market the technology.	Enhanced academic and industry research on Blockchain-related topics such as latency, throughput, size and bandwidth, versioning, hard forks and multiple forks can support mainstream adoption.
Rubbish in, rubbish out	Blockchains do not verify whether incoming data is correct or not; they just verify if the data was introduced along the protocol rules.	A clear link to the data source via personal identification means could increase accountability (and thus quality) of data input.
Data privacy/rights	The nature of Blockchain networks as an immutable record inherently contradicts the "right to be forgotten," which is a legal right in many jurisdictions.	Management of data, especially personal data, needs to be analyzed carefully before storing it on a Blockchain system.

Source: Author's own work.

3.7.1 Energy Consumption

Blockchain technology has frequently been criticized for its high energy use. However, the level of energy consumption is dependent on the type of Blockchain (i.e., permissioned or permission-less) and the type of consensus mechanism. The "Proof of Work" (PoW) consensus mechanism in permission-less Blockchains, for instance, leads to high energy consumption. Permissioned Blockchains, however, generally consume less energy because fewer participants have the right to incorporate the next block of transactions into the joint network data history.

The most widely used consensus mechanism is PoW (used by permission-less networks like Bitcoin and Ethereum). With PoW, computers on the network compete to solve mathematical formulas and win the right to propose and incorporate the next block of data into the joint network data history. Solving the mathematical formula involves a trial and error exercise. It is not possible to predict which computer will propose the next data block – all computers search for the correct hash value at the same time.

That makes it impossible for hackers to identify a single computer as a target. However, the major disadvantage is the massive energy consumption caused by thousands of computers racing to find the right hash value. Further information on the energy consumption is provided by the CleanCoin[7] project.

Currently, there are more than a dozen consensus mechanisms under development. A comprehensive summary of existing consensus mechanisms is provided by the community platform 101 Blockchains[8].

One of the most prominent alternatives to PoW is "Proof of Stake" (PoS), which uses token holders to achieve consensus and is currently developed on the Ethereum Blockchain. Those who hold tokens can temporarily lock them in a smart contract and, in exchange, participate in the consensus process, confirm transactions and receive rewards based on the relative number of tokens held.

Rewards are the economic incentives for the validation of network data. In PoW, if a participant operates 2% of the total computing power of the network, he can expect to get 2% of the block rewards. In PoS, if a participant owns 2% of tokens, he can expect to receive 2% of block rewards. Achieving consensus via the PoS mechanism only requires a fraction of the energy as the PoW mechanism, since the participating computers do not have to search and find appropriate hashes.

3.7.2 Scalability

Scalability is the ability of a Blockchain to accommodate as many users as possible on the chain while still retaining fast consensus.

Most permission-less Blockchains are currently unable to scale up their performance capacities due to inefficient consensus protocols. This inefficiency results in a few major drawbacks, one being the longer "**block time**," the time it takes to generate a set of data on the Blockchain. It determines how fast and how many data entries can be processed in a set of time.

The Bitcoin Blockchain, for example, has one megabyte (MB) block sizes[9] (about 2,000 transactions can be included in each block[10]). The competition among the so-called "miners" to solve a math formula to place a block takes 10 minutes, resulting in seven transactions per second. The public Blockchain Ethereum currently processes a maximum 20 transactions per second, while the permissioned Hyperledger Blockchain achieves up to 100,000 transactions per second. In comparison, the Visa network processes more than 65,000 transactions at the same time[11].

Energy consumption and scalability are less serious issues within permissioned Blockchains managed with some level of centralized governance. In other words, if the access to Blockchain networks is limited to only permitted participants, then the networks do not need to operate necessarily using the PoW (or PoS) mechanism and could therefore achieve much higher transaction throughput using only a fraction of the energy used by permission-less Blockchains.

However, a truly decentralized system only works properly if it has a robust and working consensus mechanism in place. Both challenges, energy consumption and scalability, are directly linked to the inherent feature of Blockchains to operate without a central governing body.

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(7) See http://www.cleancoins.io/#/info

(8) See https://101blockchains.com/consensus-algorithms-blockchain/

(9) For real-time information on the average size of blocks on the Bitcoin Blockchain, see https://www.blockchain.com/de/charts/avg-block-size

(10) For real-time information on the average amount of transaction per Bitcoin Block, see https://www.blockchain.com/de/charts/n-transactions-per-block

(11) For information on Visa transaction capacity 2018, see factsheet https://usa.visa.com/dam/VCOM/download/corporate/media/visanet-technology/aboutvisafactsheet.pdf

3.7.3 Lack of Maturity and Proven Experience

A core feature of Blockchain technology is decentralization, which can threaten the business models of well-established market players (intermediaries). Unlike global financial institutions, companies introducing a Blockchain to decentralize certain economic relationships do not have the means for marketing the technology and its features, which leads to an overall **lack of proper marketing** for the technology.

Moreover, Blockchain technology is still in its infancy. Bitcoin, the first Blockchain application, just turned 10 years old, and Ethereum, the first Blockchain able to execute smart contracts, was only launched in 2015. Academic and industry research on Blockchain related topics such as latency, throughput, size and bandwidth, versioning, hard forks and multiple forks needs to be improved to support the development and mainstream adoption of the technology.

3.7.4 Rubbish In, Rubbish Out

Blockchain technology itself is not a tool to increase data accuracy or to prevent fraud or crimes. Data transferred on a Blockchain network is copied and stored multiple times on numerous computers. The Blockchain does not verify whether incoming data is correct or incorrect, but only if it was introduced according to protocol rules. Generally speaking, that means "rubbish in, rubbish out." In order to achieve a high quality of data, the accountability of the data provider needs to be ensured. It needs to be clear who put what on the Blockchain. In that respect, ID verification approaches for humans (fingerprints, iris scans, etc.) and machines (identification processes, GPS allocation, calibration/verification of settings) still have considerable development ahead.

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3.7.5 Data Privacy/Rights

Legal principles occurring in the context of digital media, such as "the right to be forgotten," may be difficult to implement on Blockchains. Networks need to be aware of these features and design data input streams accordingly. Blockchain entries are immutable, meaning that once data is stored it cannot be altered. This has implications for data privacy, particularly where the relevant data is personal data. The nature of Blockchain systems as an immutable record inherently contradicts the "right to be forgotten," which is considered a legal right in some jurisdictions. Organizations storing personal data via Blockchain will need to carefully consider how to comply with rules relating to their handling of that data (WEF 2018).

4

Potentials and Usability of Blockchain for Climate Policy

4. Potentials and Usability of Blockchain for Climate Policy

Although a Blockchain is not a silver bullet for climate policy instruments, it may play an important role for future policy making. Many use cases based on Blockchain technology have already been implemented or are currently under development (for a comprehensive overview of use cases in the climate action ecosystem, see BORN 2018).

Blockchain should only be pursued if other conventional approaches have failed to deliver the expected benefits, or if a Blockchain can offer higher quality benefits at comparable or lower cost.

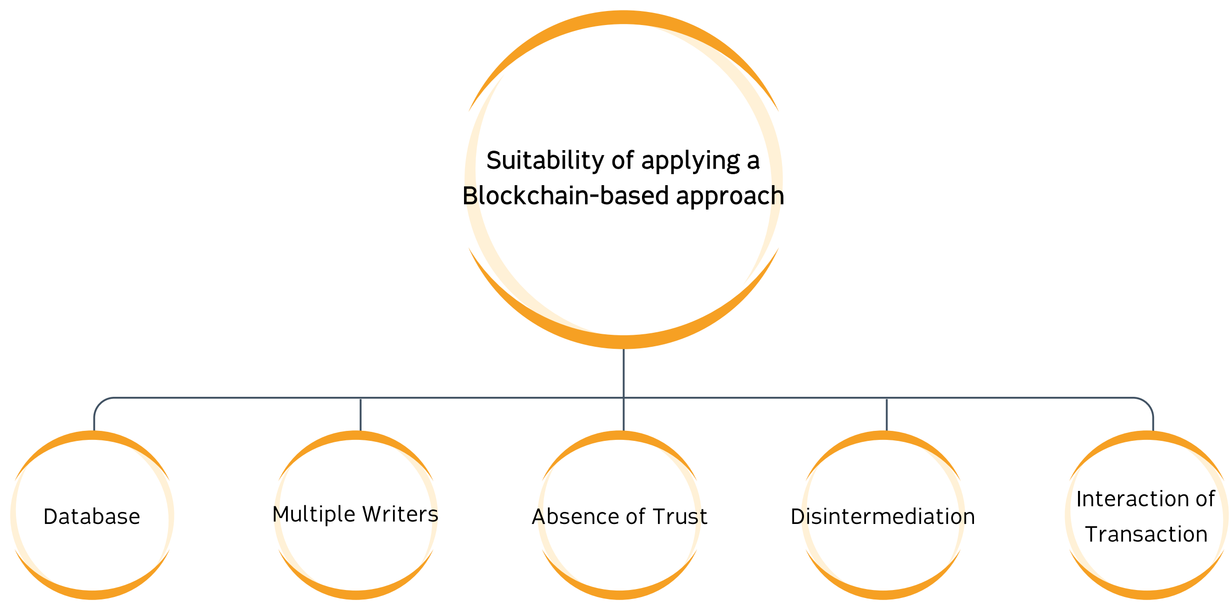
This section introduces the different features to consider when analyzing the potentials of Blockchain for a climate policy use case. As a simple rule of thumb, a Blockchain should only be pursued if other conventional approaches have failed to deliver the expected benefits, or if a Blockchain can offer higher quality benefits at comparable or lower cost. As a first step when analyzing the potential of Blockchain, the following three features should be relevant to the climate issue being addressed (BORN 2018):

1. **Disintermediation:** *Cutting out trusted third parties could increase overall efficiencies, especially in cases where the underlying problem is not centralized in nature.*
2. **Cross jurisdiction:** *Where it might not be possible to find or create a trusted third party, or it may be too inefficient to go through a trusted third party.*
3. **Reporting and compliance** applications: *Reporting, especially with regards to regulatory compliance, can be moved from time-discrete (e.g., annual) reporting to a continuous consensus process through permission-less or public permissioned Blockchains.*

In a subsequent step, Blockchain approaches should be examined against the existing or planned infrastructure/architecture. The figure below proposes a checklist[12] against which climate policy instruments can be examined:

(12) The checklist is based on in-depth exchanges with IT developers and a comprehensive desk review. For further documentation, please see Wüst and Gervais in "Do you need a Blockchain?" 2018, https://eprint.iacr.org/2017/375.pdf; Greenspan in "Avoiding the pointless blockchain project" 2015, https://www.multichain.com/blog/2015/11/avoiding-pointless-blockchain-project/; and Wesley in "Building It Better: A Simple Guide to Blockchain Use Cases" 2018, https://blockchainatberkeley.blog/building-it-better-a-simple-guide-to-blockchain-use-cases-de494a8f5b60

Figure 4. Decision tree: Suitability for Blockchain-based approaches



Source: Author's own work.

1. **Database:** Does the selected climate instrument involve a (relational) database? Multiple databases?
2. **Multiple Writers:** Does the case involve more than one entity/participant who is generating the transactions that modify the database? If the writers all mutually trust each other (i.e., no participant is malicious now or in the future), a database with shared writing access is likely the better solution.
3. **Absence of Trust:** The user does not accept modification to the joint state of the shared database by another user without further proof?
4. **Disintermediation:** Is there a valid reason/need for removing trusted intermediaries (the "middleman")?
5. **Interaction of Transaction:** Are transactions dependent on one another? Transaction interaction is required by all kinds of database systems, particularly in multi-user systems involving the exchange of assets or goods. If transactions do not interact with one another, it is more effective to use a "master/slave" database, in which one "master" node acts as the champion of validation and approval for a certain subset of transactions that "slave" nodes carry out. If transactions do rely on one another, determining how to distribute corresponding transactions among master nodes becomes quite difficult, resulting in the need for something like a Blockchain to alter the collective state of the database[13].

4.1 Evaluation of Selected Blockchain Platforms for Climate Policy

This section evaluates the usability of selected Blockchain platforms. The Blockchain networks Bitcoin, Ethereum and EOS belong to the most popular platforms with a market capitalization of 68, 12 and 3 billion US Dollar (USD), respectively.[14] The fourth network is Hyperledger Fabric, which uses permissioned nodes to build Blockchains and does not include (self-sustaining) economics in its design, meaning that Hyperledger runs without economic incentives (e.g., cryptocurrencies). The evaluation of Bitcoin, Ethereum, Hyperledger and EOS for climate policy instruments is based on five criteria:

(13) See Graham Wesley, see footnote 12 T
(14) See www.coinmarketcap.com as of 01/2019

1. **Programmability:** What degree of freedom does one have to program this Blockchain platform? Is it close to being Turing complete?[15] Is there a software development kit or another accessible environment development?
2. **Operating costs:** What are the costs to run this Blockchain? What aspects should be considered when estimating the overall costs (programming, maintenance, etc.)?
3. **Security:** Permissioned networks minimize the risk of malicious peers trying to manipulate the network. Security issues may also arise based on the coding language; the languages to program smart contracts (chain-code) on Hyperledger are Java and Go, which are well established and popular programming languages. In the case of Ethereum, its coding language is Solidity, which, owing to its high complexity, leaves a high risk of holding exploits or bugs that have not yet been found. However, Ethereum stands out in this discussion because of its widespread distribution, due to its permission-less mainet. The many users on a Blockchain increases the probability of finding bugs; less distributed Blockchains do not have enough scale to prove their resilience against attacks.
4. **Usability:** Encompasses a general appraisal about how frictionless it would be to work with a given Blockchain technology. Documentation, support and distribution play a role in this category.
5. **Trustability:** This criterion combines several factors. What does governance look like? Who writes code? How distributed is the network? How is consensus reached? *This criterion has not been considered in the evaluation process since an overall centralized governance (expressed through permissions for participation and pre-defined validation nodes) is anticipated. It should be noted that in the context of evaluating public Blockchains, "trustability" is a crucial criterion.*

Figure 5. Comparative rating of selected Blockchain networks

Each category is rated on a scale of 1-5 (with 20 total possible points), in which 1 (red) is poor and 5 (dark green) is ideal.

	BITCOIN CC	ETHEREUM	HYPERLEDGER	EOS
Programmability				
Operating costs				
Security				
Usability				
Trustability	n/a	n/a	n/a	n/a
SCORE	12	18	16	13

Source: Author's own work.

Bitcoin is not a suitable architecture for supporting climate policy instruments. The fact that it cannot execute most algorithms is a considerable limitation of programmability.

The Ethereum Blockchain platform stands out for its ability to have a self-made cryptocurrency. High usability, low operation costs and a great degree of freedom to program in Solidity make the Ethereum platform a good tool. This observation is supported by the fact that numerous Initial Coin Offerings (ICO) were executed on the Ethereum platform in 2017 and 2018. In terms of token generation, Ethereum offers an easy way to program a cryptocurrency and can be operated at very low costs.

Hyperledger was rated just below Ethereum. Hyperledger is a large platform and usable for a broad variety of use cases. Compared to Ethereum, it offers even greater flexibility to set up a customized architecture for climate instruments. The potential downside of Hyperledger is the

(15) Turing complete is a term used in computability theory to describe abstract machines, usually called automata. Such an automaton is Turing complete if it can be used to emulate a system of rules, states and transitions.

platform's setup as a purely permissioned-based Blockchain and its close link to well- established technology companies. Considering the long-term perspective of distributed ledger technology (DLT) development, Hyperledger's integrated access-control layer may become an obstacle in cases where decentralization and community building are crucial.

The perspectives on EOS are also promising, and in the future its technology approach may well become the industry standard regarding the built-in permissioned feature and the management of private keys address. However, the experiences with EOS are just too limited at this point of time. The fact that EOS offers built-in features such as authentication and account management on its public Blockchain means it is not necessary to launch a private chain version of EOS (as suggested for Ethereum below). As mentioned above, when evaluating public Blockchains the criterion of "trustability" is crucial. EOS runs on a pre-defined number of nodes that have been selected by EOS token holders (e.g., mainly the creators of EOS). In addition, operation costs on the public chain are difficult to evaluate[16] since these depend directly on the market price of the native EOS token[17].

In conclusion, after focusing on the evaluated features of programmability, operating costs and security, the Ethereum Blockchain appears to be the most suitable of the four platforms for climate policy application, followed by Hyperledger.

4.2 Which Blockchain Applications Reap the Technology's Disruptive Potential?

Some discussions on Blockchains leave the impression that Blockchain adds value for any shared database. However, as explained above, merely using a Blockchain as a shared database will likely generate more costs than benefits. Energy consumption and maintenance costs may be higher due to Blockchain's decentralized nature. In the case of a shared database, fees (or an equivalent like the access and right to process user data) will be required by a centralized administrator. In the case of decentralized Blockchain networks, entries to the ledger always imply some level of costs (e.g., transaction costs, PoW, stacked capital, etc.). This is how Blockchain networks can maintain an ecosystem without a centralized governing body.

Whether a Blockchain is a good fit will largely depend on whether the climate issue under scrutiny involves a market situation and provides for the creation of a token that can be traded and incentivize sustainable behavior in the market.

Whether a Blockchain is a good fit will largely depend on whether the climate issue under scrutiny involves a market situation and provides for the creation of a token that can be traded and incentivize sustainable behavior in the market. Developers of such a purpose-driven Blockchain network will have to carefully draft the protocol rules, keeping in mind that subsequent changes or improvements will need to be adopted by the majority of the network to become effective. The protocol rules may to some extent substitute the services of intermediates such as financial institutions (e.g., banks, clearing houses, trustees, etc.) or auditors. It can therefore be expected that Blockchain applications meet a respective demand in areas where intermediates play a crucial role – for example, in international (trade) relations with multiple stakeholders and differing business interests.

(16) See https://cryptoyum.com/discussions/cost-of-running-dapps-on-eos-is-prohibitive/ (08/2018)
(17) See https://www.coindesk.com/ram-it-all-rising-costs-are-turning-eos-into-a-crypto-coders-nightmare/ (09/2018)

5

Blockchain and Emissions Trading Systems

5. Blockchain and Emissions Trading Systems

Emissions trading is a key area of climate economics since it enables jurisdictions to put a price on the emission of GHG. The trading of emission quotas is widely seen as a way to effectively reduce emissions. In order to incentivize industrial polluters to reduce their emissions, a government sets a cap on the maximum level of emissions and creates allowances for each unit of emission allowed under that cap. Emitting companies must obtain and surrender allowances for each unit of their emissions. They can obtain allowances from the government or through trading with other companies.

The features of Blockchain technology may serve as suitable elements of Emissions Trading System (ETS) designs, especially when considering the complexity of this policy instrument. The following evaluation begins by drawing on lessons learned within ETS design and examines, at a general level, if Blockchain technology would offer a potential for application. In a second step, the evaluation examines the suitability of a Blockchain approach for a core element of emissions trading – an Emissions Transaction Registry.

5.1 Challenges of Current ETS and the Potential Role of Blockchain

The identification of challenges as well as the associated potentials for a Blockchain approach in the context of emissions trading follows the main system elements: scope, emission caps, distribution of allowances, offset policies and trading mechanisms (as identified by WORLD BANK ETS 2016a):

Table 2. Blockchain potential for ETS design elements

ETS Element	Challenge	Potential for Blockchain
Scope	Currently limited scope, with only big industrial emitters covered due to high transaction costs	Enhanced scope possible due to lower transaction cost enabled by Blockchain-based automatization of ETS processes
Emissions cap	Emission caps are the outcome of political decisions that may negatively affect long-term planning.	Embedding allocation rules and allowance amounts on a transparent Blockchain protocol may strengthen the frameworks of ETS.
Distribution of allowances	Distribution of allowances via auctioning is not transparent – this could become a problem for linked ETS.	Blockchain-based auctioning could serve as gateway or a joint layer for a network of connected national auctioning platforms.
Offset policies	Risk of double counting	A Blockchain registry jointly run by countries would ensure that generated offsets are coded into the Blockchain and reconciled with national registries.
Trading mechanism	White-collar crimes like securities fraud, insider trading, money laundering, transfer mispricing and Internet crimes	Risks may be minimized on permissioned Blockchains (with shared ledgers).

Source: (WORLD BANK, 2016a) and author's own work.

The scope of mandatory ETS is mostly limited to big polluters – for example, industrial installations that emit thousands of GHG tons per year. Small emitters are outside the scope of these regulated and capped markets, the argument being that the administrative workload of forcing small emitters under a capped carbon market does not justify the relatively limited outcome. The associated transaction costs of having to comply with mandatory trading and Monitoring (or Measuring), Reporting and Verification (MRV) rules are simply too high. However, while this argument is certainly true from an economic perspective, extending the scope of capped carbon markets to smaller emitters would contribute to higher awareness of internalizing costs of GHG emissions.

There are good reasons to assume that applying Blockchain technology to ETS could lead to a comprehensive expansion of ETS scopes in the future. The automatization of processes (via Internet of Things [IoT] – e.g., in the verification process where instant online identification of measurement devices occurs via digital signatures) leads to lower transaction costs and could therefore become attractive for regulators to include facilities with lower emissions. Blockchain technology could also facilitate the trading procedures since it provides for peer-to-peer transactions of emission units. Some companies have already embraced these new opportunities in one way or another (see use cases below).

Emission caps are based on the national circumstances. The objectives of mandatory ETS are to mitigate GHG emissions at the lowest possible cost, as determined by market forces. Emission caps that are too loose do not provide for incentives to mitigate GHG emissions. Emission caps that are too ambitious will put the sectors in question at a competitive disadvantage and may face severe objections from the affected industries and associated political forces. Finding the right balance of establishing a cap is more of a political and legal task than a technical challenge that could be solved by the introduction of Blockchain technology per se.

The establishment and maintenance of emission caps may be supported by integrating the underlying emission quotas, fixed timelines and allocation rules into smart contracts. Embedding these elements in a transparent network protocol could contribute to improving the transparency and predictability of future ETS. The functions of smart contracts for ETS could, for example, serve as core elements of future ETS linking agreements between different jurisdictions.

Distribution of allowances via auctions is based on centralized operations. Auctions rely on proprietary and closed software. As a result of this centralization, the auctioning instrument lacks transparency. Buyers of allowances have no way to ensure the origin, authenticity and legitimacy of a higher bid. Only the organizer has this information. Another challenge is the limited ecosystem of auctioning platforms; each organizer has developed its own bidder interface and tools. This may not be relevant for the domestic auctioning of allowances. However, considering that many countries aim for ETS linking, it would be straightforward to reflect these tendencies in the design of future auctioning platforms.

Blockchain technology could provide for enhanced transparency thanks to its distributed repository features. Auctioning operations can be registered within a Blockchain network in a way that is publicly verifiable and virtually immutable.

The distributed character of Blockchain networks also allows for increased interoperability. Depending on the chosen platform, a Blockchain-based auctioning client could serve as the gateway or a joint layer for a network of connected national auctioning platforms. The increased interoperability would also make it possible to link to other distributed repositories, such as those processing identity data of the involved parties. The latter aspect would make corruption more difficult since any entry to the ledger (e.g., the allocation of allowances) would need to be signed with a cryptographic private key.

Offset policies of mandatory emissions trading face challenges such as the **risk of double counting** of emission reductions. While a centralized issuance and supervision by a governmental agency may be appropriate for national offset programs, this is different for situations that involve cross-border operations. To maintain the environmental integrity of offset policies with international scopes (e.g., where offsets are created outside a given ETS jurisdiction), it needs to be ensured that such offset units are only used once.

The international exchange of emission allowances or offset credits is expected to increase in the future due to the introduction of a respective framework under the UNFCCC regarding ITMOs.

In that respect, it is the responsibility of involved countries to ensure that ITMOs are only accounted for once. The Paris Agreement obliges countries from 2020 onwards to ensure that provisions around the transactions of ITMOs prevent double counting of such outcomes (Article 6.2 and Article 6.5 Paris Agreement).

The intangible nature of carbon assets (e.g., emission allowances or offset units) enables separation between ownership of the investment project and the rights to trade the associated emissions allowances (or offset units), making **traceability** of carbon assets more difficult than for other assets derived from physical commodities. A project such as planting trees, or upgrading a factory, for example, may be owned and managed by one person or company, while another acquires the legal rights to trade any carbon asset generated.

The intangible nature of carbon assets (e.g., emission allowances or offset units) enables separation between ownership of the investment project and the rights to trade the associated emissions allowances (or offset units), making traceability of carbon assets more difficult than for other assets derived from physical commodities.

When trading across international jurisdictions, monitoring capacity is often diluted, making the illegal recycling, double counting and sale of non-existent or stolen carbon credits much more viable, with the process usually involving the suspension of trading for several days (INTERPOL 2013).

Figure 6. Hypothetical example of double counting of a mitigation outcome

Source: INTERPOL 2013.

Blockchain technology may provide a higher level of **trust and security** than conventional registries with differing tracking systems. A Blockchain registry jointly run by countries pursuing voluntary cooperation under Article 6 of the Paris Agreement would ensure that every outcome generated, issued and internationally transferred is coded into the Blockchain and reconciled with national registries. Such a network would have to be run by computers associated to the Parties that cooperate accordingly. The same universal ledger log of all transactions would be stored on every participating computer. To realize such potential, participating countries would need to agree on a common set of basic information to be stored (e.g., geographical indicator, time, mitigation, action inside or outside host country Nationally Determined Contribution [NDC]). Such system would increase transparency and data security (CMR 2017) and could ultimately decrease the risk of double counting emission reductions.

While every asset (e.g., mitigation outcome) could be given **full visibility** to the participants of the Blockchain network, only the holder of the private key associated to the asset would be able to move ownership titles in the ledger.

The **risk of corruption** is increased by the fact that there is no physical indication of the identity of the carbon asset holder, beyond a piece of paper or record in a government register. Fraud may also be facilitated by corruption that allows persons to register forged documents concerning ownership of carbon assets.

It is similarly difficult to prevent the owner of a carbon asset from selling the same asset over and over to multiple parties. Double counting is facilitated by carbon assets being sold through several foreign exchanges with different regulations and standards of monitoring or cross checking among them (INTERPOL 2013).

In the first trading period of the European Union Emissions Trading System (EU ETS), it was indeed the intangible nature of carbon assets that triggered one of the greatest tax crimes in European Union (EU) history. Between 2009 and 2011, a network of well-organized individuals from several financial intermediaries around the world made more than 600 million Euro (EUR) through a profitable carousel fraud by avoiding (and claiming the unjustified refund of) Value Added Tax (VAT). The VAT fraud was possible due to the lack of unified regulation within the EU concerning Emissions Trading Registries and anti-money laundering provisions. Blockchain technology would probably not have prevented such activities – however, if the transactions had been visible to all network participants, such criminal activities would have been detected a lot earlier.

Trading mechanisms of mandatory carbon markets are managed based on centralized Emissions Trading Registries on specific IT architectures that allow the web-based transaction of units, for example, from the accounts of the sellers to the accounts of the buyers.

The carbon market faces the same vulnerabilities as other financial markets. Examples of potential exploitation include white-collar crimes such as securities fraud and insider trading, embezzlement, money laundering, transfer mispricing and Internet crimes.

White-collar crimes are (to a large extent) based on the distribution of false information, either regarding the associated risks of investments or the origin of financial flows. However, these crime-related activities do not necessarily depend on how values are transferred between different stakeholders and may happen with or without Blockchain technology.

Another challenge is the weakness in the Internet security of Emissions Trading Registries, which has been exploited by criminals to steal emission allowances. The electronic nature of emission allowances and their registries make ETS particularly susceptible to technology crimes such as hacking. Although emission allowances can be identified through unique serial numbers, making it possible to track stolen allowances, this can be undermined by weak regulatory oversight, particularly when stolen allowances are traded across different jurisdictions.

Although trades are regulated through the national authorities or international bodies (e.g., under the UNFCCC) and tracked via an international transaction log, the data is still vulnerable to Internet theft and fraud (INTERPOL 2013).

The distributed nature of ledgers on a Blockchain makes it difficult for hackers to attack the network (and the underlying market). Even though ETS are particularly vulnerable to technology crimes, it should be noted that most ETS-related incidents are due to Internet theft (e.g., identity theft). These crimes are not an exclusive problem of centralized registries. Owners of online wallets within Blockchain networks have been targeted by hackers in the past and will be targeted in the future. Ownership rights of tokens on Blockchain networks are executed via private-public key pairs. Losing the private key to any account on the Blockchain is equal to the permanent loss of funds in that account. There is no way to recover these funds; since a centralized service provider is lacking, it is crucial to take care of the private keys associated to account wallets on the Blockchain. Such risks may be minimized on permissioned Blockchains, because participants would need to have a permission for entering the network. However, holders of such permission may also be subject to Internet crimes such as identity thefts.

Blockchains can contribute to increased accountability of their users due to the requirement that transactions are signed. In addition, ID measures for signing transactions (fingerprints or iris scans) combined with cryptography will improve online security, while retaining data privacy.

5.2 The Potential Role of Blockchain for an Emissions Transaction Registry

As already indicated, Blockchain technology should only be pursued if other conventional approaches fail to deliver the expected benefits, or if it can offer higher quality benefits at comparable or lower cost. That is particularly relevant for the role of the middleman.

The Emissions Transaction Registry is a key requirement of any ETS and provides services that are usually allocated to a trusted middleman (e.g., government or a trusted third-party agency). The registry is a database that records serialized issuance of emission allowances and offset units as well as any other information specific to the respective unit. This can include the vintage, the identity and, where appropriate, the location of the project for which the unit was issued. The registry also provides for the transfer of units (internally) between account holders and/or for the transfer of units (externally) from one transaction registry to another (WORLD BANK, 2016b). It is through the registry that participating entities can demonstrate compliance with the ETS rules.

So far, conventional approaches for transaction registries have served their purpose. All current ETS registries have centralized operations (via a designated Registry Administrator) and only occur within their system boundaries. Whether the nationally administered and centralized governance structures seamlessly link with other systems and programs remains to be seen. In any case, the decentralized elements show strong benefits with respect to ETS linking[18]. The following figure lists both advantages and disadvantages of a centralized and a decentralized registry architecture.

(18) See, for example, Macinante et al. in "Networked Carbon Markets: Permission-less Innovation with Distributed Ledgers?" 2017, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2997099

Figure 7. Centralized and decentralized registries – benefits and disadvantages

Advantageous   Neutral   Disadvantageous

	Allowances/Offset Units	Account Management
Centralized Executed by Registry Administration	Allowances/offset units are reflected via database entries by Registry Administrator.	Accounts are managed by Registry Administrator; he also provides associated services (e.g., lost password, hotline, etc.).
	Changes (e.g., reflecting allocation/surrendering) to database are always possible – the supply power is centralized.	
	Use of data beyond ETS is relatively limited – this increases complexities for linking system with other systems/ programs outside the registry boundaries (avoidance of double counting of allowances/offset units).	
Decentralized Executed by smart contract and network protocol	High interoperability since fungible/non-fungible token approach may offer efficiency gains through increased interaction of data with other databases (linking).	Management of private keys for allowances/offset ledger not trivial (e.g., lost private keys cannot be recovered without considering pre-defined additional security measures).
	Allowances/offset units are reflected via tokens within a smart contract – once the total amount of allowances/offset units is generated, any later adjustment will mean a new setup of the underlying smart contract.	

Source: Author's own work.

The benefits and disadvantages of both centralized and decentralized registry systems are relatively balanced. The centralized approach is well in line with governmental core tasks such as allocation of allowances and management/supervision of registry accounts. When it comes to the data transaction itself (allowances, offset units or verified emissions), it is the tokenization of units related to the ETS that promise new and enhanced capabilities, including increased interoperability. This is especially true for cross-border transactions or those between different systems (Article 6 Paris Agreement and CORSIA [Carbon Offsetting and Reduction Scheme for International Aviation]). As long as an ETS is purely focused on domestic trading of emissions, a centralized database seems to be the more appropriate choice.

However, ETS data may be used for more than exchanging emission quotas. Linking ETS data to GHG inventories via a hybrid approach combining a permissioned Blockchain (token transaction) and a centralized layer (account management) can automate processes, lower ETS transaction costs of entities and facilitate international linking.

A Hybrid Approach – The Crypto Exchange Analogy

Ownership of cryptocurrencies is expressed via the access to a private key of the dedicated crypto token (e.g., Bitcoin, Ether, Litecoin, etc.) managed by so-called "online wallets." Wallets can be downloaded online and installed on a desktop or smart phone. These wallets hold the information to the ledger entry where the crypto-coin is saved. Only the owner of the private key can change the entry of the ledger. Generally, there is no way to recover a private key once it is lost. Decentralized networks by definition do not have dedicated hotline services; decentralization comes with a high level of self-responsibility.

Platforms like Kraken[19] or Coinbase,[20] where cryptocurrencies can be bought and sold, offer their customers accounts (user name and password access) on their exchanges to buy, sell or simply hold cryptocurrencies like Bitcoin or Ether. In these cases, the private keys to the respective coins (tokens) are stored on the servers of the exchanges (Kraken or Coinbase). In technical terms, it is the platform that has access to the private keys of the respective tokens. Every account holder at Kraken or Coinbase can withdraw tokens from the platform. The benefits of these centralized exchanges are their positive user experiences, including forgotten password services and the fact that most of them are insured against hacks and loss of private keys.

The business approach of crypto exchanges could well serve as a blueprint for the architecture of future Emissions Transaction Registries. It would combine the best from both sides, centralized and decentralized[21]. Allocation of allowances, acknowledgement of offset units and registry account management would be managed on the centralized database (Transaction Layer). The generation and distribution of tokens (with different characteristics) on dedicated administrative wallets happen on a permissioned Blockchain (Blockchain/Settlement Layer).

Transactions within an Emissions Transaction Registry depend on each other. Allowances and offset units, for example, are both eligible for achieving compliance in an ETS. However, such compliance needs to respect the pre-defined limits to offset use. Hence, allowances and units depend on their relative interaction when being surrendered. Interaction of transactions is also foreseen in cases where an Emissions Transaction Registry holds units that represent emissions that would have to be neutralized by dedicated allowances.

The Governing Layer needs to ensure that the amount of allowances, offset units and emission units matches the total amount of tokens generated on the Blockchain Layer. In the case of national trading activities, transfers may only need to be recorded on the Transaction Layer within the centralized database. In situations where allowances or offset units are outside the boundaries of the ETS, the respective units have to be effectively marked as booked-out on the Transaction Layer, and the token needs to be withdrawn from the registry platform (e.g., the Blockchain/Settlement Layer).

The advantage of this hybrid model is that the capabilities of the Blockchain Layer may be gradually and subsequently enhanced by the respective development of the underlying smart contract (rules setting, fixation of token specifications, etc.). The majority of ETS activities will take place on the centralized Transaction Layer.

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The middleman is required to ensure the proper functioning of the account system as well as to help maintain flexibility regarding ETS events like allocation of allowances or acknowledgment of offset units.

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The initial question regarding the need for eliminating the middleman can therefore not be answered with a simple yes or no. The middleman is required to ensure the proper functioning of the account system as well as to help maintain flexibility regarding ETS events like allocation of allowances or acknowledgment of offset units.

(19) See www.kraken.com

(20) See www.coinbase.com

(21) Assumptions of the hybrid approach are more relevant for activities on the Ethereum Blockchain. The Hyperledger approach may not need specific centralized layers for account management.

The application of permissioned Blockchain technology for the setup of an Emissions Transaction Registry is a suitable approach.

The application of permissioned Blockchain technology for the setup of an Emissions Transaction Registry is a suitable approach. Based on a hybrid approach, it is suggested to be applied for the generation of different tokens that represent

- a fixed amount of emission allowances;
- a dynamic number of offset units; and
- verified emissions of ETS entities.

These tokens will be held in dedicated administrative wallets (on the Blockchain/Settlement Layer). They are linked to companies' accounts on the centralized Transaction Layer.

5.3 Related Use Cases

Blockchain-based use cases that implement (mandatory) Emissions Trading Systems as described above are still missing. However, Blockchain-based use cases relevant for voluntary carbon markets already exist.

The Canadian start-up CarbonX[22] offers financial incentives for individuals to reduce their carbon footprint. CarbonX buys carbon offsets and "convers" the offset into a cryptocurrency token called CxT.

These tokens are sold to retailers and manufacturers, who in turn use them to encourage consumers to make more sustainable choices. Consumers using the CarbonX platform might earn tokens for choosing locally grown products instead of flown-in goods, or for buying an energy-saving washing machine. CxT tokens can be exchanged for carbon friendly goods and services, other reward program points or other digital currencies. The loyalty scheme uses Blockchain technology to keep track of the transactions.

Retailers decide how many tokens a given purchase will earn, and the tokens are tradable on the CarbonX platform. Retailers and service providers signing up for CarbonX can also take advantage of transaction data and information on customers' energy usage to help them target products and services to the customers most likely to purchase them (NEVES 2018).

The use of tokens that represent emission reductions is also at the core of initiatives like Climatecoin,[23] Veridium[24] and Earth Token[25].

Blockchain technology increases the transparency and trust of finance flows that contribute to GHG abatement within specific mitigation projects. It can be questioned whether the tokenization of carbon assets will increase the overall amount of project-related GHG reduction activities in the short-term. However, in the mid-term, these initiatives may provide additional financial liquidity to both voluntary and mandatory carbon markets. Moreover, these companies will further increase their capabilities to interoperate with other market players and data providers. This may allow them to analyze and evaluate the performance of companies regarding their claims in terms of environmental and social responsibilities.

(22) https://www.carbonx.ca/
(23) https://climatecoin.io/
(24) https://www.veridium.io/
(25) https://www.earth-token.com

6

Blockchain for Tracking Climate Mitigation Efforts and Climate Finance Flows

6. Blockchain for Tracking Climate Mitigation Efforts and Climate Finance Flows

In the climate change field, the term MRV stands for monitoring/measuring, reporting and verification of GHG. MRV is the process of collecting monitored data and collating it in line with standardized or non-standardized approaches to report progress on emissions reductions, the impact of a given measure or policy, or climate finance flows. MRV systems are an essential element of climate policy as they provide transparency to stakeholders on the status quo and support ambition raising. Consequently, MRV is seen as a common feature of climate economics, be it in the context of emissions trading, carbon taxes, environmental labeling or carbon footprint disclosure.

For the purpose of this paper, three types of MRV systems are distinguished (adopted from WRI 2016):

- MRV of GHG emissions, conducted at national, organizational and/or facility level to understand an entity's emissions profile and report it in the form of an emissions inventory.
- MRV of mitigation actions (e.g., policies and projects) to assess their GHG effects and sustainable development (non-GHG) effects as well as to monitor their implementation. This type of MRV focuses on estimating the change in GHG emissions or other non-GHG variables.
- MRV of support (e.g., climate finance, technology transfer and capacity building) to track provision and receipt of climate support, monitor results achieved and assess impact.

This chapter analyzes the potential of Blockchain technology for all three types of MRV, with section 5.1 focusing on MRV systems for GHG and for mitigation actions, and section 5.2 focusing on MRV systems for climate finance.

6.1 Blockchain and MRV of Emissions and Mitigation Actions

The identification of challenges and the associated potentials for a Blockchain approach in the context of MRV of emissions and mitigation action are summarized below:

Table 3. Blockchain potential for MRV of emissions and mitigation action

Challenge	Potential for Blockchain
Lack of transparency	Greater transparency of how the data is collected and reported through the use of shared ledgers displaying relevant MRV parameters
Costly and impractical	Coupling the benefits of a decentralized database with smart contract applications and IoT can help automate processes, thus lowering transaction costs and reducing complexity.
Time consuming	Blockchain technology and decision making via smart contracts makes IoT more attractive; verification can become a rolling approach where data is checked automatically or in real time.
Limited exchange of MRV frameworks (data silos)	Storage of MRV raw data on a Blockchain (following a joint protocol) could lay the ground for connecting MRV frameworks and end the era of data silos.

Source: Author's own work.

6.1.1 Challenges of Current MRV of Emissions and Mitigation Actions

MRV is often **costly and impractical**, particularly where the collection of spatially diffuse or hand-collected information is involved, as this drives up the cost of collection and audit. Another major cost category is verification of data, which is typically done by a qualified and competent professional who conducts onsite visits. As a result, rather than investing in activities that improve the project or policy measure themselves, MRV often ends up spending significant amounts on activities that do not directly reduce emissions.

MRV processes are also **time consuming**, often meaning that results-based finance or offset units are delivered several months after the fact. Such costs serve as a barrier to many projects.

Access to primary data from the project site can be cumbersome. Projects are often located in difficult-to-reach areas where historic data may be scarce or non-existent. Collection of data for baseline conditions can therefore be very difficult. **Gaps in data** may occur where data is lost or inaccurate or where environmental or political issues prevent site access. Poor site conditions and accessibility, as well as the lack of access to competent staff, can lead to data inaccuracy, bias and **transparency issues**, and affect the reliability and timely delivery of the information. Finally, **human error** is common for projects conducting MRV.

There are several ways to **manipulate MRV** processes. Most obviously, the data can be intentionally misreported. More subtly, information analysis can be distorted by measuring only certain variables, selecting certain sites for data collection or adopting certain assumptions in MRV reports (CLI, 2018b).

6.1.2 Potential Role of Blockchain

Blockchain Technology can provide **greater transparency** about how the data is collected and reported and how the combination of parameters leads to the determination of GHG reductions (and the subsequent issuance of carbon credits). In current practice, it can be difficult to extract specific data points from the project documentation and to review how they were collected and checked. But with Blockchain technology, each parameter and collection point can be turned into a specific block, making them easily viewed and checked. Some care would still need to be taken to protect data privacy of, for example, household technology.

Blockchain Technology can provide greater transparency about how the data is collected and reported and how the combination of parameters leads to the determination of GHG reductions

One of the implementation challenges of the Internet of Things, particularly in remote areas, is the cost and practicality of doing so. In isolation, the application of IoT technology presents little benefit in relation to the overall efficiency of the MRV process (since reporting and review happen on a milestone basis). However, through Blockchain technology and smart-contract-based decision making, **IoT becomes more attractive**, as verification can become a rolling approach where data is checked automatically in real time. Renewable energy projects, for instance, are well positioned to take advantage of Blockchain networks for emission reduction calculation and verification purposes, as their data collected to meet MRV requirements is relatively accessible (e.g., emission factors, production data).

However, in the context of climate issues, for many countries IoT and the use of sensors is still costly and challenging. Lack of skilled people, limited Internet access in rural areas or challenges related to technological architecture are further concerns that may slow down the adoption of broad and rapid IoT.

The above features could be built as an app: Allowing users **facilitated access** to review data from a smartphone (e.g., via easy-to-handle applications) could be a way to implement the above feature while addressing some of the identified challenges. Currently, most of the relevant information is held in documents, accessible via a registry that is not mobile-enabled. By creating an app-based approach, users can review information on the move, an important benefit given the highly mobile nature of working in this field (CLI, 2018b).

Coupling the benefits of a decentralized database with smart contract applications and the IoT (e.g., direct information from gas or power meters) may help **reduce risk and complexity** associated with future carbon markets (CMR 2017).

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Tokenization within Blockchain-based MRV systems can incentivize data gathering and sharing (e.g., within industry sites). By creating a demand for tokens that carry specific information for MRV-relevant processes, the overall (public) access to climate-relevant data can be facilitated.

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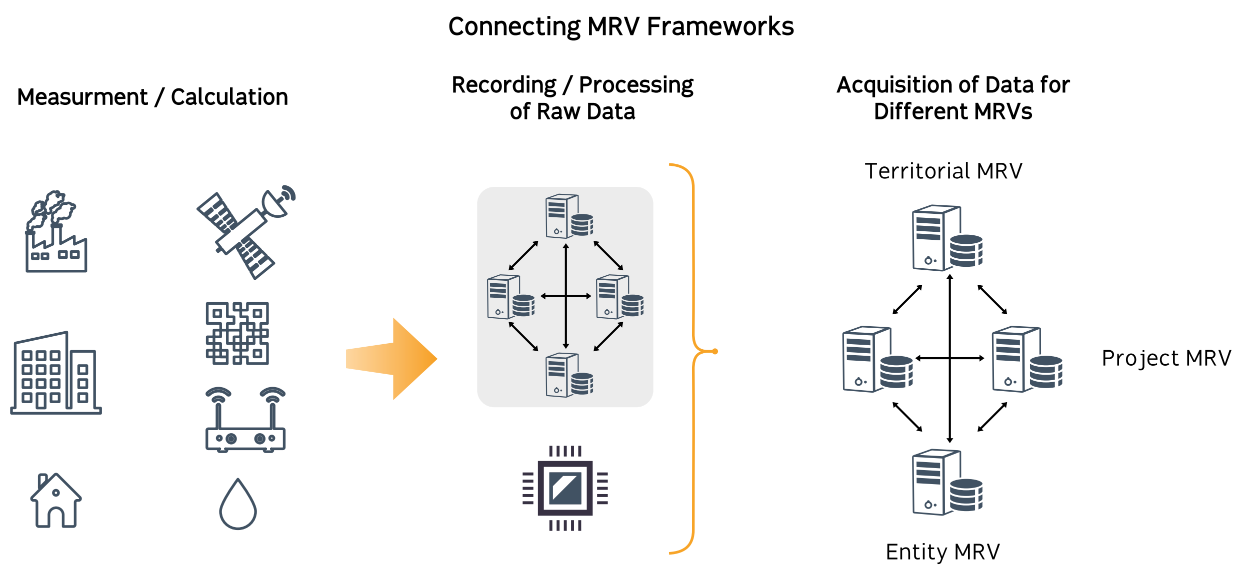
Tokenization within Blockchain-based MRV systems can incentivize data gathering and sharing (e.g., within industry sites). By creating a demand for tokens that carry specific information for MRV-relevant processes, the overall (public) access to climate-relevant data can be facilitated.

Finally, the variety of MRV systems at different levels and policy frameworks mostly work on separate streams, generating centralized data silos and preventing the exchange of data. Sharing MRV data in decentralized networks could trigger interactions between existing MRV frameworks and put an end to data silos. For example, data relevant for territorial emissions could be checked against data from other MRV frameworks (e.g., MRV results of projects or MRV of entities under an ETS) and vice versa. Independent of the MRV framework that acquires the data, the corresponding data gathering could be ensured using common standards. These standards would ensure that the storage of raw data (which measurement devices were used, calibration settings, time and GPS information, etc.) follows a joint protocol. Connecting MRV frameworks via a Blockchain could enable the instant verification of monitoring, measuring and reporting processes. The term MRV may then have to change to VMR (Verified Monitoring and Reporting).

Figure 8. Connecting MRV frameworks via Blockchain



Source: Author's own work.

The exchange of data would increase the overall quality of MRV frameworks. For example, the performance of projects and policies can be improved through instant data comparison and analytics. Potential exists to use data from projects or policies to inform the verification of future mitigation activities and to spot trends over time. Blockchain technology could enable the instant comparison of accurate data across national and sub-national jurisdictions and provide reliable data to machine-learning algorithms.

6.2 Blockchain and MRV of Climate Finance

While there is no single definition of climate finance, in its broad understanding it refers to the flow of international and national public and private funds towards activities that reduce or mitigate GHG emissions or help communities adapt to the impacts of climate change. Climate finance will also play an important role in helping developing countries meet the UN's Sustainable Development Goals by 2030. The identification of challenges as well as the associated potentials for Blockchain approaches in the context of MRV of climate finance are summarized as follows:

Table 4. Blockchain potential for MRV of climate finance

Challenge	Potential for Blockchain
Lack of transparency due to weak infrastructure, capacity limitations and cash-based systems	Functions of a smart contract can be displayed in code on the Blockchain for all network participants to check. This way, every participant can clearly anticipate the agreed funding processes.
Many intermediaries, high costs and risk of corruption	Maintaining a shared ledger facilitates the corresponding requirements of bookkeeping and accounting for climate finance. It may decrease the number of intermediates and associated transaction costs, and decrease risks of corruption.
Overlap of different donors	Overall tracking of international funding, including a clear reference to participating donors, could be enabled by executing funding decisions along pre-defined conditions recorded on distributed ledgers.
Limited possibilities to link payments to concrete results	Blockchain-based tokenization can improve results-based payment systems, where a token may represent the verified reduction of a specific amount of GHG emissions or another tangible sustainable development claim.

Source: Author's own work.

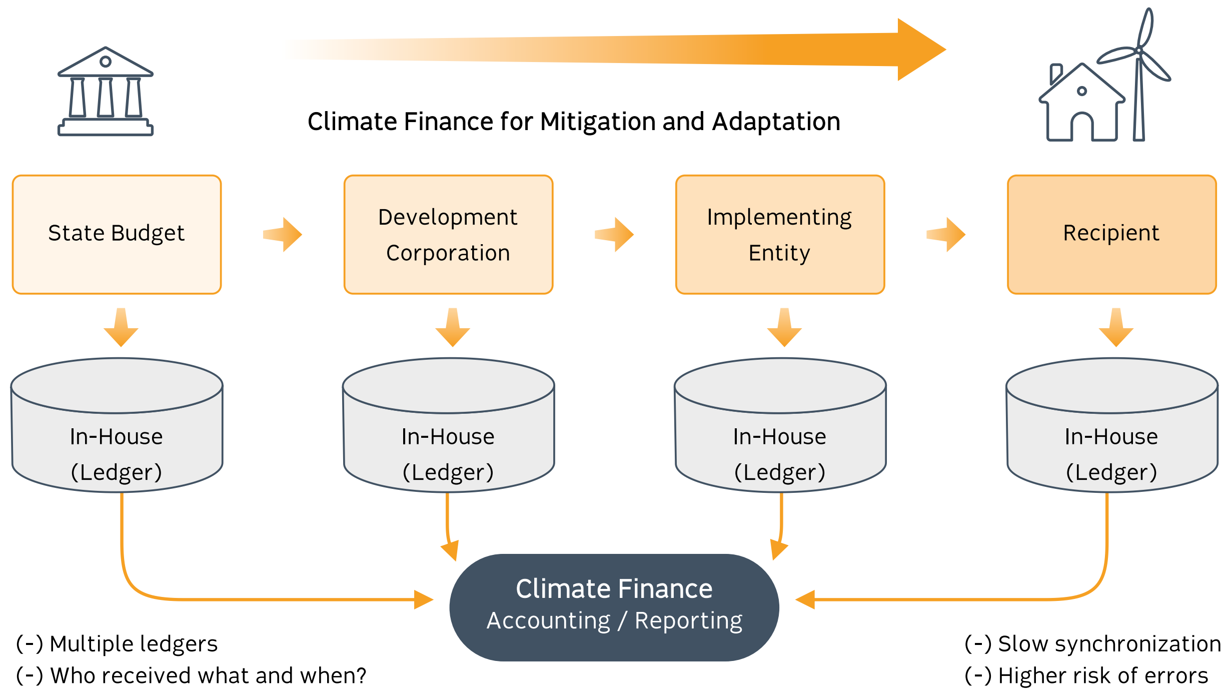
6.2.1 Challenges of Climate Finance MRV

Each year, billions of dollars flow from individuals, governments and businesses to address the challenges of climate change across the world. The distribution and tracking of global climate finance remain complex, opaque and hugely inefficient. Transfers can take weeks to arrive, and associated losses are not uncommon.

Lack of transparency in climate finance represents a key challenge for effectively tracing the flow of funds from end to end. The UN estimates that up to 30% of official development assistance is lost due to fraud and corruption. The result is less funding, which reduces the impact for those who need it most. On the ground, organizations face multiple barriers for ensuring full transparency of fund distribution; weak infrastructure, capacity limitations and cash-based systems limit the capacity of international agencies and local organizations to be fully accountable to both their donors and the communities and individuals they work with (THOMASON 2018).

Further challenges that may have negative impacts on the envisaged outcomes of climate finance flows include corruption, many intermediaries, overlaps among **different donors** and the difficulties of **linking payments to concrete results.**

Figure 9. Simplified illustration of current climate finance flows



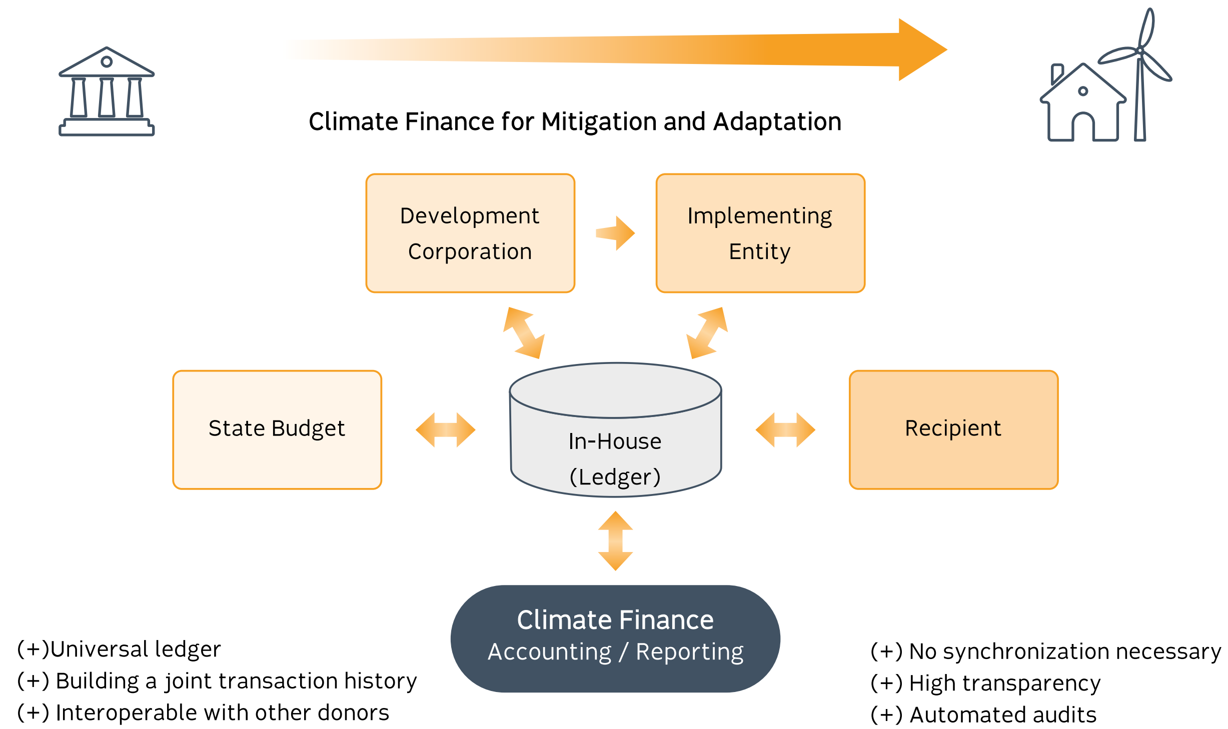
Source: Author's own work.

6.2.2 Potential Role of Blockchain – Increasing Transparency

Blockchain-based solutions could provide **transparency and security** to climate finance initiatives. Blockchain networks enable the tracing of climate finance in such a way that all participants of a given project can follow (almost in real time) the flows from donor to recipient via a universal ledger. Applying smart contracts to such a network would add an additional level of transparency to the process. Smart contracts set the conditions for the execution of transactions. Their underlying functions can be displayed in code on the Blockchain for all network participants to check. This way, every participant can clearly anticipate the agreed funding processes. If event (A) takes place (e.g., the operation of a rooftop solar system at a given GPS location), then event (B) will be executed (e.g., the release of a tax-relief token to a pre-defined wallet address). Funding decisions would be shifted away from closed meetings and be based on a pre-defined condition recorded on distributed ledgers. The approach would also allow for **overall tracking of international donor funding.**

Blockchain networks enable the tracing of climate finance in such a way that all participants of a given project can follow (almost in real time) the flows from donor to recipient via a universal ledger. Applying smart contracts to such a network would add an additional level of transparency to the process

Figure 10. Climate finance flows using a universal ledger – every participant has its own ledger copy



Source: Author's own work.

The fact that Blockchain ledgers are accessible to all network participants in real time facilitates the corresponding requirements of bookkeeping and accounting for climate finance. Processes operated by smart contracts would therefore not only **decrease** the risks of corruption and the number of intermediates but also the associated **transaction costs.**

Embedding climate finance in a Blockchain network could also allow beneficiaries to monitor public policies, performances of intermediaries or project results to provide timely feedback for impact assessment. Here, Blockchain technology could contribute to both transparency and linking payments with impacts. Firstly, it could be used by governments as a platform where the results of a given environmental policy are registered, making it available for oversight by society. This would help ensure transparency, accountability, security and quality of data. Secondly, a Blockchain-based solution facilitates the link of payments to concrete results via a decentralized platform. Beneficiaries of climate finance such as individuals, communities or entities could input their feedback peer-to-peer in a safe and reliable way, while making it available to others.

Embedding climate finance in a Blockchain network could also allow beneficiaries to monitor public policies, performances of intermediaries or project results to provide timely feedback for impact assessment.

6.2.3 Potential Role of Blockchain – Enhancing Existing Finance Models

The ongoing **digital technology** revolution has already provided certain **baseline conditions** for Blockchain solutions to advance, such as the evolution of mobile phones and the mass adoption of smartphones, and increasing Internet coverage, sometimes even in remote areas. There are now projects that employ technologies to help alleviate poverty and promote financial inclusion, for example, by offering financial services via smartphones. The adoption of Blockchain could improve the efficiency, scale and cost-effectiveness of such projects.

Blockchain technology could also enhance existing finance models such as crowdfunding by adding transparency and traceability to the process. Additionally, it generates **new funding** models, such as the ICOs, which are especially popular among start-ups that struggle to raise money through traditional financial institutions. However, in 2018 global financial market authorities began taking a closer look at ICOs since they can circumvent intermediaries and regulatory compliance. Originally created to allow "fans" and supporters to fund a given project, the ICO generally works by selling a token that, once the project is launched, represents a cryptocurrency of a functional unit that can be used in a project service or platform. If proper enabling regulations are adopted, ICOs could prove to be a powerful tool for civil society groups, communities, project developers and start-ups to access climate finance resources generally outside their reach.

Additionally, local currency tokens could be issued by regional governments or a funding entity (see example use case of the Brazilian Development Bank [BNDES] below) to ensure that the resources of a given fund would only be able to circulate within a community – between the local recipients of the program and the accredited local business. This would address two complex issues often constraining this type of initiative: falsification of the local currency and hefty fees charged by banks or financial institutions to operate the project resources.

Another aspect of currency token is their ability to operate independently from national banks and governmental control. While financial market authorities may see this as a challenge, especially regarding Know-Your-Costumer (or Client) (KYC) provisions and anti-money laundering regulations, it needs to be acknowledged that cryptocurrencies offer one of the rare alternatives to securely move values (cryptocurrencies) within jurisdictions where governmental control of monitory policy has failed and, for example, led to hyperinflation.

6.3 Related Use Cases for Tracking Climate Mitigation Efforts and Climate Finance Flows

6.3.1 Using a (Public) Blockchain for "Proof of Existence" – The Global Notary Use Case

Data stored on a public and truly decentralized Blockchain network can be compared to the legal datasets of a notary, especially when it focuses on providing a "proof of existence" (the confirmation that a certain dataset existed at a given time).

Data can be stored on Blockchains in cleartext, or encrypted or hashed. The most common form of taking advantage of the notary feature is by generating a hash of a specific dataset and embedding that hash on-chain.

A hash of some data (e.g., the digital fingerprint) is created by applying a cryptographic hash function to the original data. These functions are non-reversible, and the resulting hash is normally of fixed length. The hash never contains the original data, and the original data cannot be recreated from the hash. The hash can be attached to (or ticked off) as a transaction that will be copied and stored multiple times onto the nodes of the Blockchain network. After the network embeds the hash into one of its blocks, the information can be considered safely stored (i.e., immutable). The network now carries the digital and timestamped fingerprint that proves that a certain piece of data existed at a given point of time.

Hashes and their associated notary features are a core property of many Blockchain-based business solutions and can serve to support verification processes within MRV systems addressing both climate mitigation efforts and climate finance flows.

6.3.2 Ixo Blockchain for Impact

A Blockchain-based infrastructure for an MRV infrastructure is currently provided by the ixo Foundation, a non-profit open-source software development foundation that runs the ixo Blockchain for Impact.

Ixo has developed a protocol for a Blockchain network where measurable activities that have an impact can be transformed into so-called "verified impact data" with crypto-economic Proof of Impact. Platform users pre-define the conditions that should apply to verify specific claims, for example, within a governmental policy framework or within self-organized community programs. Any project can self-certify its impacts, which effectively scales the underwriting process for impact finance, allowing small and remote projects to access global capital markets for social finance (STANFORD 2018).

In addition, ixo will make the generated (and verified) data available to its platform, called the Global Impact Ledger. The latter is an open data commons that can be accessed by anyone, enabling governments, researchers, funders and organizations to make more informed decisions about their work and how to optimize the results of the underlying activities.

The scope of the ixo Foundation focuses on positive impacts for sustainable development and can therefore also be used as a framework for tracking climate mitigation efforts and climate finance flows. In September 2018, the project developer South Pole together with the Gold Standard Foundation teamed up with the ixo Foundation to develop an application that will "facilitate the MRV of data for compiling GHG inventories and originating carbon credits."[26]

According to the press release, "the project aims to demonstrate the feasibility of such an application at a solar photovoltaic (PV) project bundle in Thailand. This application protocol serves as a means of submitting verified data and automatically issuing certified carbon credits."
https://ixo.foundation/

6.3.3 BNDES Token and TruBudget

The Brazilian Development Bank had its first experience with Blockchain in early 2018. After a long period of studying the potential use cases in national and international fields, the bank developed the Blockchain initiative through two projects.

The first project is based on a private network developed in partnership with the German Development *Bank Kreditanstalt für Wiederaufbau* (KfW). The second project is creating tokens for the bank's public financing processes using the Ethereum network.

BNDES established a Memorandum of Understanding with KfW in February 2018, allowing it to use and collaborate on the improvement of Germany's Blockchain-based workflow management tool called TruBudget. KfW provides BNDES with consulting and technical support and intends to consolidate its open-source software licenses. The Amazon Fund, a REDD+ initiative supported by the governments of Norway and Germany – and managed by BNDES – was chosen for a proof of concept in a test environment. Real data and process information about the Amazon Fund disbursements were documented on TruBudget. The tool allows for the real-time sharing of information between BNDES and the donor side with high levels of trust. However, TruBudget is still operating in a pilot phase with a reduced scope and a small number of Amazon Fund projects in the first semester of 2019.

The BNDES token originated from a simple but very powerful idea. When a loan is released, it is done through a tokenized-backed asset, in such a way that the monitoring of all transactions can be done in real time, both by BNDES agents and by civil society as a whole.

"It is important to emphasize that, although there are some trade-offs in any application like this, the use of Blockchain technology in this case guarantees the added transparency and full traceability benefits for everyone involved in these processes. That is, these benefits are not only restricted with regard to financial operations at national and supranational levels but also have clear and positive impacts for all the final beneficiaries" (NEVES 2018).

(26) See press release from 09/2018: https://www.southpole.com/news/south-pole-partners-with-ixo-on-blockchain

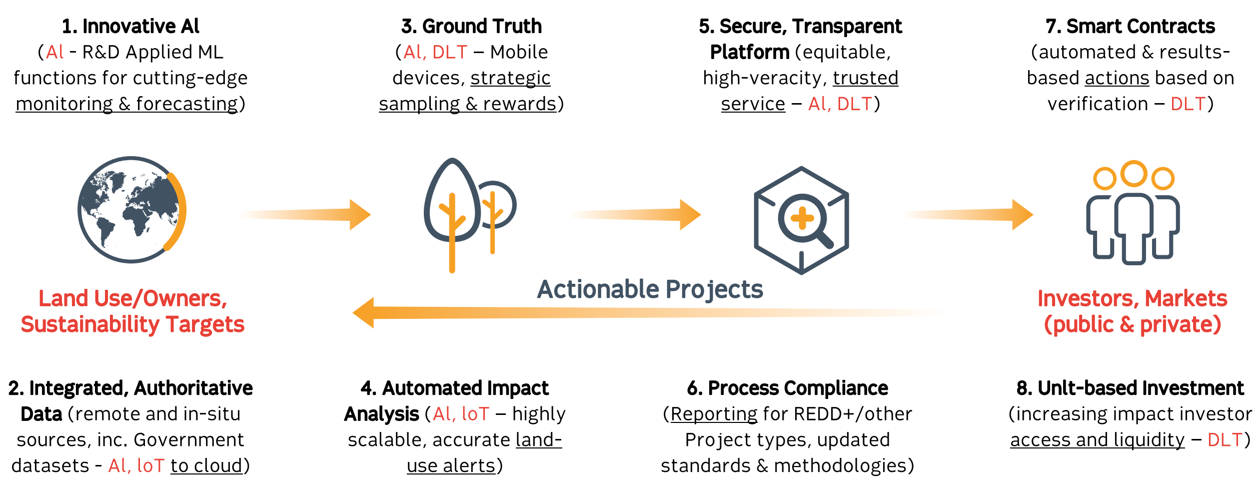
The proof of concept was developed in 2018 and involved two clients, the regional government of Espirito Santo and Ancine, a Brazilian Film Agency. BNDES and Ancine have decided to develop the pilot project further in 2019. https://www.bndes.gov.br

6.3.4 The #REDD-Chain Project

The #REDD-Chain Project (RCP) is a land-use management initiative, powered and based on the IoT–DLT–AI troika of technologies. RCP provides a platform that integrates and transforms diverse sources of satellite-, drone-, sensor- and stakeholder-captured information – bringing high-veracity monitoring and forecasting to standardized processes in order to enable faster, more effective changes on the ground.

The goal of RCP is to improve MRV accuracy and offer better-informed intervention targeting. Moreover, RCP may increase transparency and trust through benchmarkable outcomes and incentive mechanisms that open up access to new kinds of financing and lower transaction costs.

Figure 11. Representation of the #REDD-Chain Project



Source: #REDD-CHAIN, 2018.

By leveraging diverse data sources and putting them to work, RCP will enable actionable projects with trusted, automatable processes, including performance-based payments. The core of RCP will be operated as a not-for-profit platform, catering primarily to governments, while at the same time allowing various private sector stakeholders to interact.

The first pilot proof of concept has commenced in Chile, focusing on forest management in the Valdivia region.

Partners include the Chilean government's National Forest Corporation (CONAF) and the Inter-American Development Bank.

RCP intends to increase its functionality in Chile, as well as in additional pilot locations in other countries. As data availability improves, RCP also aims to expand its reach beyond forests to other land-use types, including agriculture.

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7

Conclusion

7. Conclusion

The benefits of Blockchain technology are based on cryptography and decentralization. This combination helps to achieve a higher level of trust. The application of mathematics in the process of achieving consensus about the content of decentralized and distributed database makes Blockchain technology agnostic to cultural, religious or historical preconditions and thus universally applicable.

Blockchain technology could increase transparency around the allocation of emission allowances (improved auctioning procedures) and support the implementation of integrated offset programs.

Regarding climate policies, the technology may be well suited to address major challenges, such as increasing efficiency of domestic climate actions or improving transparency in climate finance. The examination of Blockchain technology for the development of future ETS revealed great potential. Automated processes may lead to lower transaction costs, which in turn could enhance future scopes of emissions trading. Moreover, Blockchain technology could increase transparency around the allocation of emission allowances (improved auctioning procedures) and support the implementation of integrated offset programs. With respect to the suitability of a Blockchain-based approach for an Emissions Transaction Registry – a core element of every ETS – the conclusions are twofold. For the purpose of domestic registry activities, the conventional centralized management approach appears to be more straightforward than a decentralized registry architecture. Governmental core tasks such as allocation of allowances and management of registry accounts need to be executed with full access rights. Regarding the transaction of allowances, offset units or verified emissions, the tokenization of units promise new and enhanced capabilities, including increased interoperability. This is especially true for transactions that will take place across jurisdictions or between different ETS. In order to enable the best from both centralized and decentralized approaches, a hybrid approach is suggested. Current use cases are focused on the tokenization of emission reductions within the voluntary market.

Blockchain technology can contribute to the improvement of MRV frameworks related to climate mitigation efforts and climate finance flows. The automatization of program and project cycles occurring on transparent Blockchain networks has the potential to lower existing transaction costs considerably.

Blockchain technology can contribute to the improvement of MRV frameworks related to climate mitigation efforts and climate finance flows. The automatization of program and project cycles occurring on transparent Blockchain networks has the potential to lower existing transaction costs considerably. Blockchain technology also allows users to share data while still retaining control, which in turn allows for the connecting of MRV frameworks. The result could lead to an improvement of overall data quality. Climate finance may also benefit from Blockchain technology since it enables new ways for donors to interoperate. Last but not least, the tokenization of climate outcomes or impacts appears to be an attractive tool within results-based climate finance. Promising use cases that directly link financial flows with verified mitigation outcomes are already under development.

The unique characteristics of decentralized network architectures currently come with downsides, such as slow transaction management, limited governance options or higher overall network costs.

However, Blockchain technology is still in its infancy. The decision to apply a Blockchain approach for a specific climate policy instrument should be based on a thorough evaluation. The unique characteristics of decentralized network architectures currently come with downsides, such as slow transaction management, limited governance options or higher overall network costs. Building a climate instrument on a decentralized and distributed Blockchain network will have to balance the applicable pros and cons against conventional and centralized approaches.

Nevertheless, the identified potential of Blockchain applications for climate policies is promising. In order to realize the potential, Blockchain technology needs to interact with other areas of today's digital development (e.g., IoT and machine learning). Academic and industry research is needed to develop appropriate standards and respective regulation to unleash the full potential of such digital ecosystems. Finally, international cooperation for continuous knowledge exchange is required to ensure that the development of Blockchains and associated digital technologies reflect endeavors that respect sustainable development and common values.

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