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Blockchain for sustainable energy and climate in the Global South

Use cases and opportunities

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Executive Summary

The United Nations' Sustainable Development Goal 7 (SDG 7) on Affordable and Clean Energy has the ambition of ensuring universal access to affordable, reliable and modern energy services, as defined in its Target 7.1. Energy access is critical for improving living standards in local communities and supporting broader socio-economic development. More sustainable forms of energy also must be scaled up to meet long-term targets for reducing climate-altering emissions under the Paris Agreement and under SDG 13 on Climate Action.

In the face of these challenges, blockchain is an emergent technology that has significant potential to manage the data underpinning distributed clean energy infrastructure. With the help of additional emergent technologies, blockchain could also be applied to address the challenge of growing diversity in climate market mechanisms, by supporting interconnections between individual climate markets at the transnational, regional and national levels.

This report aims to provide a clearer understanding of blockchain solutions in addressing energy and climate mitigation issues, with a focus on low- to middle-income countries. The analysis targets energy and climate policymakers and business professionals who are keen to see the potential uses of blockchain in these areas. Chapter 1 explores the concept of blockchain and its general application in the energy sector, while Chapter 2 provides specific case studies to draw key policy insights on blockchain's application. Chapter 3 explores a potential road map to accelerate the clean energy transition using blockchain. It also presents overarching lessons for scaling up the use of the technology in countries around the world.

In the clean energy arena, blockchain can support peer-to-peer energy trading within decentralized energy systems, so that the use of renewables can be optimized. The technology would enable frictionless trading built on "smart contracting" and other key features, as shown in the use cases implemented by Power Ledger in Thailand, India and Malaysia (section 2.1).

In addition, the use cases of EW Origin in Turkey, Thailand and El Salvador (section 2.2) highlight blockchain's ability to support a decentralized marketplace for renewable energy attribute certificates. Because such markets in developing countries suffer from high administrative costs and dependence on intermediaries, among other challenges, it is essential to develop a transparent and accessible market that is affordable for renewable energy project developers to participate in.

Blockchain technology can also create a financing option, with Sun Exchange's micro-leasing marketplace in South Africa bringing individual and corporate energy investors to off-grid energy development (section 2.3).

The report also looks at specific business cases in the areas of carbon offset trading and the digital measurement, reporting and verification (MRV) of greenhouse gas emissions. ECO2 Ledger (section 2.4) uses blockchain technology to make carbon credit data more reliable and traceable in the voluntary carbon market in China, improving the efficiency of trading and reducing the costs of carbon credit transactions and validation. ECO2 Ledger stimulates climate actions not only from private and public sector organizations but also from individuals.

Moreover, distributed ledger technologies enable the digitalization of MRV in combination with enhanced sensor networks. Digital MRV solutions automate MRV procedures and reduce the complexity involved in conventional, highly manual data collection, reporting and verification processes, as illustrated by IOTA's solution being piloted in Chile (section 2.5).

Building on the case studies, section 3.1 displays a potential road map to accelerate the clean energy and low-carbon transition with the application of blockchain, providing a framework for linking climate financing with robust climate accounting, where blockchain offers trusted integration and automation. Smart contracts and tokenization provide the opportunity to lower the cost of management when connecting top-level financial instruments such as climate bonds with bottom-up, community-based climate action projects. Internet-connected sensors, artificial intelligence and blockchain would enable the digitization of MRV as well as a nested accounting framework that would make it possible to include the actions of non-state actors in countries' greenhouse gas inventories under the Paris Agreement.

Table 1. *Key insights from case studies*

Use case	Description
Peer-to-peer energy trading ► section 2.1	• While penetration of renewables is increasing, reckless additions can cause a host of issues for energy networks. These issues include, among others, frequency instability, network congestion and voltage disturbances. • There is a need to add renewable energy in a fit-for-purpose way to extract the maximum benefits while maintaining system reliability and without government subsidies. • Peer-to-peer energy trading allows energy produced from renewables to be assimilated locally. Through the creation of a network of localized energy markets, dynamics can be better managed while providing value to all stakeholders involved.
Market platform for renewable energy certificates ► section 2.2	• Blockchain-based market platforms for energy attribute certificates can incentivize the leveraging of renewable energy investment to create an alternative revenue stream for renewable energy projects in the post feed-in tariff era. • Blockchain can be efficiently leveraged in renewable energy markets with the help of its open-source tool to build digital platforms for easily registering users and devices, tracking renewable energy, and issuing, trading and claiming corresponding energy attribute certificates in a regulatory-compliant way. • The public sector's engagement in pilot projects is important to ensure alignment between solutions and energy market requirements and to complement policy goals.
Micro-leasing marketplace ► section 2.3	• Blockchain-based financing platforms enable the distribution and receiving of funds in digital currency between various investors – such as individuals, corporations and foundations – and the recipients of these funds, while increasing transparency. • Blockchain-based platforms allow individual and corporate energy investors to buy solar cells that power businesses and organizations in sunny emerging markets and earn money from the clean electricity generated. • Enhanced efficiency and transparency are assured in energy and climate finance flows.
Trading of carbon offset credits ► section 2.4	• The tokenization of carbon credits enables them to circulate on a carbon trading platform based on blockchain. • A lack of policy frameworks may lead to a lack of inter-operability among blockchain solutions for carbon markets. Guidelines regarding blockchain data structures, token standards, the legal nature of tokenized carbon credits, privacy and other aspects would help scale up blockchain solutions. • International and inter-industry cooperation and collaboration are essential to advocate for global blockchain-based infrastructure for climate action, comprising multiple stakeholders and protocols.
Digital MRV ► section 2.5	• Structured data collected via digital sensors (the Internet of Things) and secured in distributed ledger technologies in combination with digitized MRV methodologies increases the trust and utility of the data to support more efficient and effective decision-making and solutions for climate and sustainability. • Continued developments of digital MRV in individual sector climate actions, including energy, transport, industry, agriculture and others, are essential to bring key learnings on the way to scaling up the solution. • While digitalizing MRV can reduce the total costs surrounding conventional MRV, it adds the upfront costs of distributed ledger technologies and Internet of Things devices that require digital literacy to use. The costs and benefits should be assessed when considering adoption of the technology.

The case studies also highlight five overarching lessons, related to local capacity, data governance, digital infrastructure, technological development, and policy and regulatory concerns. These are summarized as follows.

1. **There is a lack of digital literacy and capacity among enterprises and the public sector to leverage blockchain for energy, climate and sustainable development.** To tackle these challenges, technology-oriented innovation hubs in countries have contributed to steering social learning to nurture local capacity and to help identify local sustainability challenges where blockchain digital technologies can be translated into solutions.

2. **It is important to ensure enough volume of qualified data to be used in the blockchain applied in the energy and climate change domains.** In itself, blockchain does nothing to improve the reliability of the data inputs.

3. **Driving the penetration of blockchain and relevant emergent technologies requires improving the digital infrastructure**. This includes having affordable broadband internet access and smart devices.

4. **Given that blockchain is still in its infancy, it is important to look not only at its positive implications, but also at potential negative environmental impacts from its use.** The technology itself also needs to evolve to be applied to foster environmental sustainability or at scale, overcoming the challenges of scale and speed and a "trilemma" between scalability, decentralization and security.

5. **It is important to create and implement policies and regulations that are not counterproductive to innovative solutions for sustainable development**, while at the same time preventing any risks brought through them. Regulatory "sandboxes", in which solutions that build on blockchain and other innovative technologies could be tested in a controlled environment, can be beneficial to examine and explore the feasibility and challenges of applying blockchain to the relevant domains. The sandboxes can be used to explore the policy and regulatory implications from actual use cases.

All in all, challenges remain in successfully deploying innovative solutions such as blockchain in an inclusive and equitable way, especially in the Global South. Digital infrastructures in low- and middle-income countries are frequently not sufficiently developed and maintained, and evident obstacles remain for technological development and its thorough use. Furthermore, blockchain and other emergent technologies must always be designed following human-centred approaches. The challenges facing communities should guide the development of solutions, and community members should be part of the design, use and evaluation of digital solutions. Even if new technologies can offer alternatives, these solutions will only be effective if they can be operated on the ground, employing or developing local capacities.

• Introduction

The United Nations' Sustainable Development Goal 7 (SDG 7) on Affordable and Clean Energy strives to ensure universal access to affordable, reliable and modern energy services, as defined in its Target 7.1. Energy access is critical for socio-economic development and for improving the living standards of communities. It is also strongly interconnected with other development goals (McCollum *et al.* 2018), including ending hunger (SDG 2) and ensuring quality education (SDG 4) and decent work (SDG 8). Globally, the share of the population with access to electricity increased from 83 per cent in 2010 to 89 per cent in 2017 (International Energy Agency [IEA] *et al.* 2019); however, the electrification rate remains low in developing countries (*World Bank* 2018a). Further, according to Sustainable Energy for All (2020), the global COVID-19 pandemic has also highlighted the vital importance of access to electricity, which is essential for disease prevention and pandemic control, including providing electricity to healthcare facilities, as well as clean water for essential hygiene.

Despite a record 4 per cent drop in global energy demand in 2020 due to the COVID-19 pandemic, and a resulting 5.8 per cent reduction in energy-related carbon dioxide (CO_2) emissions (the largest annual percentage decline since World War II), the sector still emitted 31.5 gigatons of CO_2 that year (IEA 2021a). This energy use and resulting emissions are directly linked to the current climate crisis and *the* surpassing of planetary boundaries (Steffen *et al.* 2015). Monthly analysis has shown that as the first wave of the pandemic was brought under control and economic activity increased, global emissions also increased, reaching levels In December 2020 that were 2 per cent higher than a year prior (IEA 2021b).

Despite gradual reductions in the costs of clean energy in recent years, an accelerated and scaled shift towards a more sustainable energy system is still required globally to meet climate targets under the Paris Agreement and under *SDG* 13 on Climate Action (UNIDO 2018). CO_2 emission reductions up to 2030 are expected to come mostly through technologies that are already on the market, but the pathway towards net zero emissions in 2050 *will* require the help of new and emergent technologies (IEA 2021b).

Distributed ledger technologies – including blockchain technology – have been proposed as an alternative to manage the data that underpin distributed clean energy infrastructure (Teufel, Sentic and Barmet 2019). Distributed ledger technologies comprise digital infrastructure and protocols that immutably enable simultaneous access, validation and record-keeping across a network. Among these, blockchain is a type of software in which digital transactions are grouped together into blocks (United Nations [UN] 2020a).

Although decentralized energy systems are cost-effective alternatives for clean electricity access in rural communities (IEA 2017; UN 2018), the intermittent nature of renewable energy generation has been identified as a barrier to scaling up the deployment of decentralized clean energy (International Renewable Energy Agency [IRENA] 2019). Blockchain can address this challenge by managing, in a decentralized way, the distributed energy value chain, from the generation of electricity, to distribution, to final consumption (IRENA 2019). It can serve as an enabling technology for scaling energy systems powered by distributed energy resources that lack a central grid operator (Zhai and Lee 2020), enabling participation in collective, local energy structures (UN 2021a).

Blockchain technology, combined with Internet of Things applications, can automate electricity-consuming systems, battery storage and other grid services at the individual or industrial levels (International Finance Corporation 2018). Blockchain builds on its distributed and immutable ledger to trigger, track and settle transactions within such systems. Blockchain can also address the growing number of (usually isolated) climate market mechanisms by supporting interconnections among climate markets at the transnational, regional and national levels (World Bank 2018a). In parallel, work is required to ensure that blockchain technology is itself energy efficient and does not consume a disproportionate share of energy resources that would outweigh the benefits it enables.

The elements necessary to make blockchain successful – such as a robust governance structure, technology systems infrastructure, and the capacity to manage and train stakeholders

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– require a contextualized analysis. In some locations, such elements are not yet in place or conducive to a blockchain system. Given the emergent stage of blockchain applications, a comprehensive and impartial outlook is essential to assess not only opportunities, but also potential threats arising from the use of the technology, along with contextual requirements needed to fully profit from its potential – in every region of the globe.

Within this nexus, this report explores the use of blockchain as an enabler of sustainable energy and climate-friendly applications, highlighting specific use cases from low- to middle-income countries, or from economies in transition and developing economies[1]. In doing so, it showcases how blockchain-based solutions can help countries leapfrog their energy systems and climate solutions.

Throughout, the report aims to provide energy and climate policymakers, as well as business professionals interested in blockchain applications in low- to middle-income countries, with contextualized knowledge on how blockchain can be applied. Topics covered include energy trading; renewable energy certificates (RECs); energy and climate financing; measurement, reporting and verification (MRV) of greenhouse gas emissions; and the trading of carbon offset credits.

Chapter 1 provides an overview of blockchain technology and its application to decentralized energy management and financing. Chapter 2 describes how blockchain can be applied in the energy and climate fields through case studies covering the above-mentioned topics. Building on this information, Chapter 3 concludes by suggesting a concept of a cohesive, blockchain-based system that accelerates the clean energy transition. It then proposes a road map to scale up the technology equitably in countries.

1 The United Nations' World Economic Situation and Prospects classifies countries into three categories: developed economies, economies in transition and developing economies. See UN (2020b).

1. Blockchain and Its Application to Energy and Climate Change Mitigation

1.1 Blockchain technology[2]

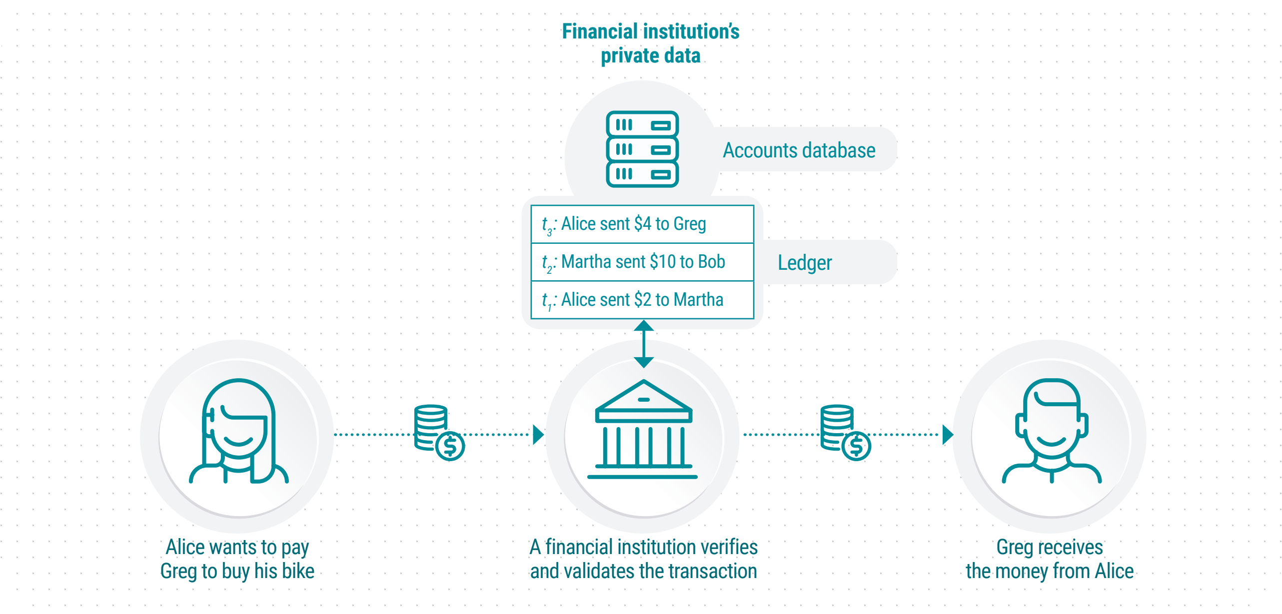
Trust issues and the creation of blockchain

Information and communication technologies (ICT) have changed the fabric of our society, impacting almost every aspect of our lives. They have influenced the way we communicate both personally and professionally, our entertainment activities, how we connect and interact with each other and get involved in our communities, and how governments and institutions make strategic decisions.

From their inception, value transactions online have relied almost exclusively on financial institutions, serving as trusted third parties. These institutions maintain centralized databases with information on clients and their account balances. Some of these databases are ledgers[3] that keep a log of financial transactions. In such a model, financial institutions own, administrate, and control the databases and ledgers showing these transactions (figure 1). The administrator decides who can access the data and who can modify it, being responsible for the security and integrity of the data.

Such institutions usually have different mechanisms to ensure the reliability and accuracy of transaction data. However, with systems based on a central node, tampering can theoretically be done without verification from actors that are outside of the private ledger. In parallel, financial scandals involving financial institutions – such as the collapse of Lehman Brothers in 2008 – have weakened the trust of individuals in these institutions (Montgomery 2012).

Figure 1. Money transfer through a trusted third party



2 This content was prepared by Rafael Angarita (Institut supérieur d'électronique de Paris (ISEP)).
3 According to the Cambridge Dictionary, a ledger is "a book in which things are regularly recorded, especially business activities and money received or paid".

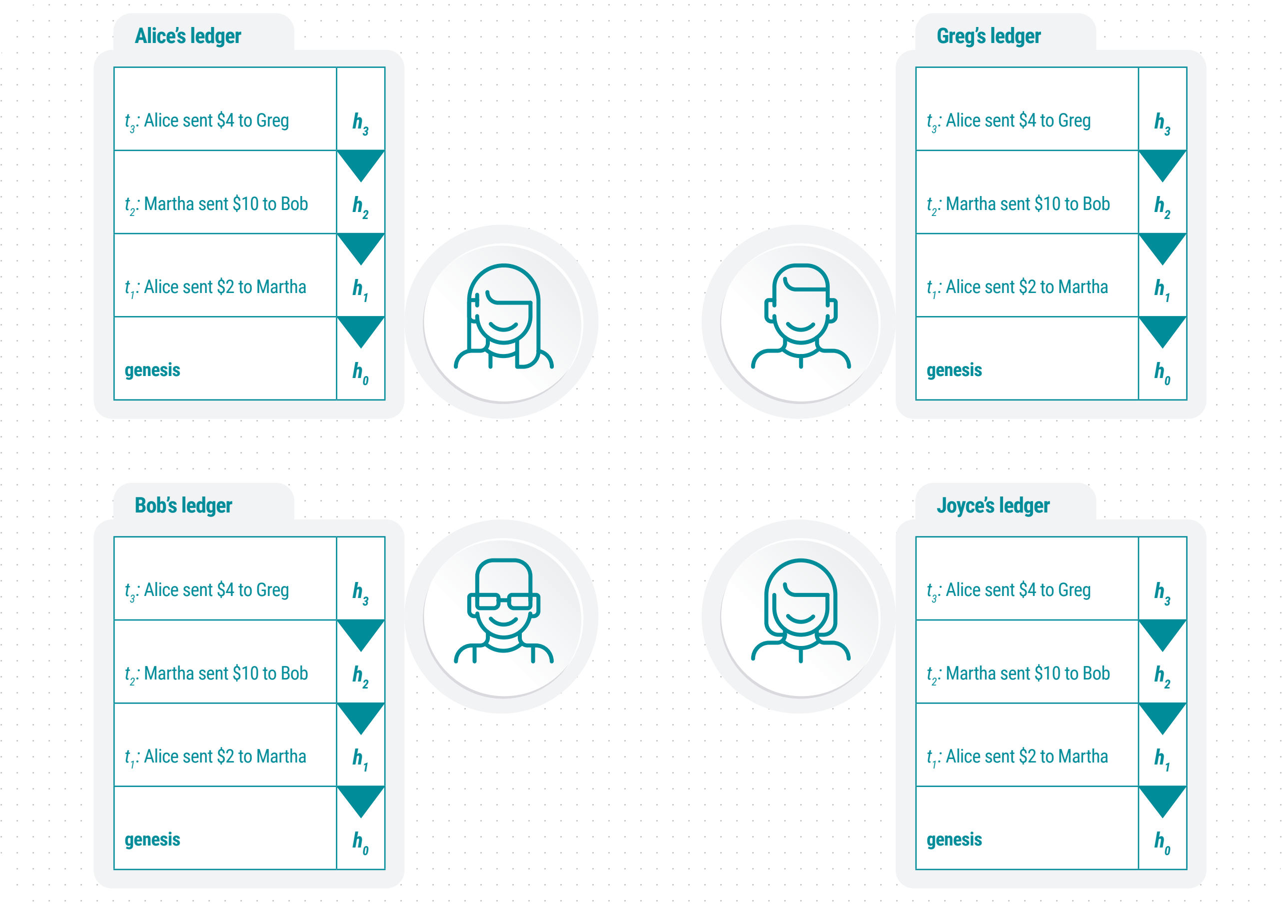
As an alternative to the centralized, trust-based approach, in 2008 – the same year as Lehman Brothers' bankruptcy – Satoshi Nakamoto published a paper describing the Bitcoin digital cryptocurrency (Nakamoto 2008). A few months later, he started the first blockchain, or distributed ledger technology. A blockchain is an immutable distributed ledger that is shared across a network of computers called peer nodes, where every peer maintains a copy of the ledger containing every transaction since the beginning of the network. Blockchain users own and transfer crypto-assets (Yaga *et al.* 2018) – such as cryptocurrencies, or coins – in the network. The goal is to let peers transact, without the need for an intermediary financial institution, through consensus (the transaction is executed once all parties agree) and by independently validating the transaction by each peer within the chain.

Particularities of blockchain technology

Figure 2 illustrates a ledger distributed among four peers in a network. This ledger has three blocks containing the same three transactions as our previous example, plus a starting point block called the genesis block, which does not contain user transactions. Along with the transactions, each block also contains a hash value produced by a cryptographic hash function (Preneel 1994) that takes data as input and produces the hash value. It is a one-way function, so that no one can find the original input from the produced hash value.

We can consider a hash value – a function that converts letters and numbers into encrypted and fixed-length information – to be a summary of the data. In a distributed ledger, each hash value is produced using the data of the block and the hash of the previous block, creating an immutable chain of blocks – hence the name "blockchain". For instance, suppose that a malicious peer modifies the amount of money that Martha sent to Bob in "transaction 2" (t_2). He must compute a new hash value for h_2; however, h_3 is now outdated since it was computed using the previous value of h_2. This causes the chain of blocks to be broken. To fix it, the malicious peer would have to recompute all the successive hash values and convince the other peers that its ledger is the right one, which is not a feasible task, especially at scale.

Figure 2. A ledger distributed across four nodes



The nature of distributed ledgers gives rise to the most relevant properties of a blockchain, which include the following (Wüst and Gervais 2018):

- **Decentralization:** This is a key property, since there is no central authority that owns the data; instead, the data are distributed among the peers, hence the name "distributed ledger".
- **Transparency:** Every peer knows the data and the processes for access and updating them.
- **Public verifiability**: Since there is transparency, any peer can verify the correctness of the state of the distributed ledger.
- **Integrity:** Since there is transparency and public verifiability, any peer can verify the integrity of the distributed ledger.
- **Redundancy:** This comes from the fact that the ledger is distributed, and every peer has a copy of it, increasing the resilience of the blockchain to attacks.
- **Immutability:** Thanks to the above properties, it is practically impossible for any entity to manipulate, replace or falsify data stored on the network.

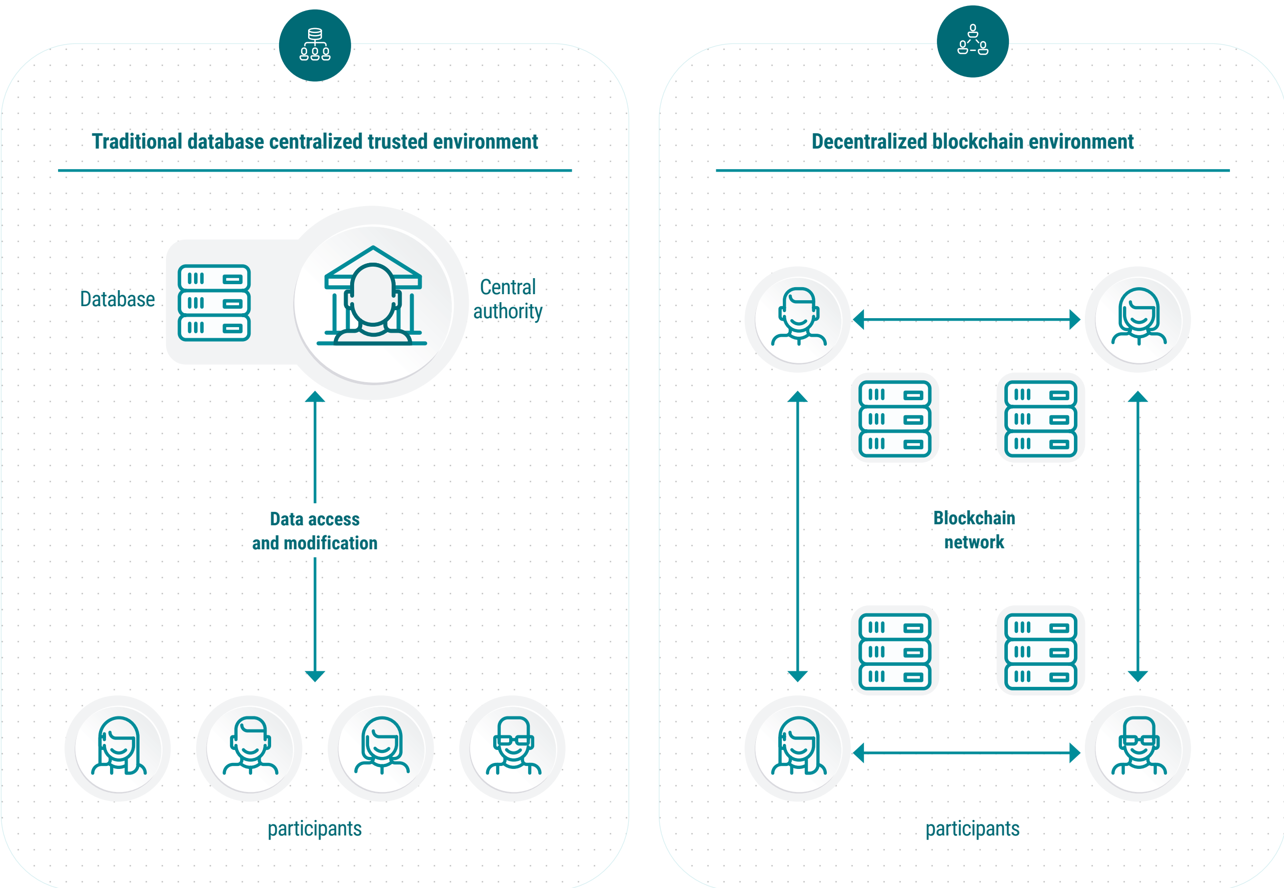
Figure 3 illustrates the two different models of traditional, centralized databases and distributed ledgers.

Box 1.

Blockchain types: permissionless and permissioned

Blockchain was born as a permissionless technology, granting the same power of influence to all network members. In a permissionless blockchain, also known as a public blockchain, the consensus allows all users to have equal rights, such as access to the data, the creation and validation of transactions, and the production of new nodes. In contrast, permissioned blockchain, also known as private or consortium blockchain, has gained interest across various industries. In permissioned blockchains, the consensus does not always allow all users to have equal rights, meaning that the levels of power across the network need to be granted. This reduces the redundancy of blockchain processes, eventually improving scalability, increasing the speed of transactions and consuming less energy.

Figure 3. Traditional versus decentralized ledgers



Blockchain beyond finance

Following the decentralization of the finance sector, blockchain has also been used to decentralize environmental management, voting, digital identities and value chains, among other areas (Pilkington 2016; Le Sève, Mason and Nassiry 2018). Decentralization brought by blockchain facilitates traceability and enables reliable monitoring of value chains. This can respond to challenges in a “circular economy” by tracking the flow of resources and materials and identifying opportunities to reinforce feedback loops and circularity processes (UNEP 2020).

All in all, blockchain is an alternative to centralization and its limitations. Decentralization of systems can reduce the risk of corruption, fraud, and manipulation, as different users have access to the information and are responsible for its integrity. Moreover, blockchain has the potential to reinforce the reliability and traceability of policy, regulation, and official documentation, in particular in developing countries; it becomes an obstacle to document forgery and in the context of weak institutions (Pilkington 2016; Kshetri and Voas 2018). Furthermore, blockchain can automate certifications of authenticity of data and optimize the operations of governmental and private organizations.

While recognizing blockchain’s multiple possibilities, this report focuses on its applicability to energy and climate issues.

1.2 Blockchain’s application to energy and climate solutions[4]

There is growing interest in rapid decarbonisation and decentralisation of the global energy sector. However, renewable energy sources are often variable, meaning that they are dependent on intermittent weather conditions. This has led to new challenges in the management and operation of electricity systems, and necessitates having appropriate monitoring tools to ensure the management of demand and supply.

The renewed determination of multiple countries to deploy smart meters would create the necessary infrastructure for accurately monitoring demand and supply from “prosumers”, or people that act as both producers and consumers of electricity. Coupled with the need to enable data exchanges among multiple actors in the network, this necessitates a gradual shift from a centralized network management system towards more decentralized and digitised energy networks. Distributed ledger technologies such as blockchain are primarily designed to facilitate distributed transactions without a centralized management entity. In this regard, distributed ledger technologies can emerge as the underlying technology to foster the necessary changes in energy management infrastructure, especially for clean energy distribution and associated financial transactions.

Smart contracts to automate business logic

In many cases, blockchain is applied in the energy sector to execute complex tasks, building on its functionalities. One example is the use of a “smart contract”, or a computer programme that codifies business logic to automate the execution of particular transactions (Luu et al. 2016; Cong and He 2019; Mik 2019). The objectives of smart contracts are to bypass or reduce the need for trusted parties, avoiding manual mediation and arbitration, and hence reducing costs. Smart contracts have gained popularity in part with the development of the Ethereum blockchain (Buterin 2013) – the second largest cryptocurrency platform, behind Bitcoin – since it advocates and facilitates the creation and deployment of smart contracts. When applied to energy transactions, smart contracts automate payments of charges, levies, fees or remuneration of energy trading, for example, which can reduce the documentation processes between the energy supplier and consumer.

In other blockchain use cases, crowdfunding is leveraged to increase climate financing. In crowdfunding, a fundraiser raises external financing by asking for small amounts of money from a large “crowd” of individuals, rather than soliciting large amounts of money from a small group of investors (Belleflamme, Lambert and Schwienbacher 2014). The crowdfunding application is expected, for example, to execute the following business logic automatically: send the collected money to the fundraiser if the goal is met, or refund individuals if the goal is not met. This business logic can be expressed as computer code within a smart contract. Similar to a distributed ledger, a smart contract is distributed, so no one person maintains it once executed; it is transparent to all peers, and no one can tamper with it.

Potential of blockchain technology in clean energy and climate action

The recipe for energy market decentralization lies in harnessing a combination of blockchain technologies, artificial intelligence and the Internet of Things (e.g., smart meters), alongside affordable renewable energy production (e.g., rooftop solar panels) and storage equipment (e.g., batteries). This requires a certain local environment to enable the use of technology, such as digital literacy, capacity and infrastructure. Blockchain can help simplify the pricing structure and ascertain the origin of the renewables through peer-to-peer trading in a community grid. The potential of blockchain technology in the clean energy sector can be assessed through economic, technological, and social lenses, with dimensions on both the demand side and the supply side.

4 This content was prepared by Alastair Marke, Sai Kishore Nellore, Mihail Mihaylov, Jenya Khvatsky, Hayden Postle Floyd and Thomas Symes (Blockchain Climate Institute).

Blockchain technologies can support demand-side management of a distributed energy network in three main ways, described as follows.

1. **Blockchain facilitates a significant reduction in transaction costs.** The current energy trading system is dependent on intermediaries and associated costs for processing the transactions, leading to inefficiencies and high friction. A blockchain-based system can facilitate transactions of small quantities of electricity at speed with low friction. For example, the key functionality of Ethereum smart contracts is to eliminate the need for each transaction to be validated by any intermediary, as the smart contracts run on predetermined codes in an automated manner.

2. **From a technological point of view, blockchain technology simplifies many transactional processes.** For example, smart contracts automate payments of charges, levies, fees or remuneration, etc., which can reduce the documentation processes between the energy supplier and consumer. Today's participation of diversified entities in the energy market pushes the existing infrastructure to its limits, as decentralisation is substantially lowering the market entry threshold for smaller energy suppliers. Blockchain technology can facilitate more accurate load monitoring, generation and distribution in the grid through efficient use of data collected by digital devices such as smart meters.

3. **From a social viewpoint, the traceability and transparency offered by blockchain technology provide unique social value**. Consumers can become cognizant of the source of their electricity, and governments can become aware of price manipulations, because all of the transactional information associated with the energy (including consumption patterns) is stored in blocks viewable by consumers.

On the supply side, blockchain offers two core benefits in the management of energy dynamics. Firstly, by enabling small trading transactions, it can facilitate greater numbers of prosumers in the energy market, leading to increased participation of multiple stakeholders (see section 2.1). Secondly, it facilitates the trading of renewable energy certificates (RECs) that provide proof of green sources of electricity (section 2.2), using the key features of blockchain networks. Because transactions in the distributed ledger can originate anywhere and propagate across all points in the network, blockchains are an excellent fit with a decentralised model of production and consumption. Every power meter, battery and solar panel can have an identity and transaction history, all recorded in a tamper-proof flow of transactions.

Further, blockchain can help scale up energy and climate financing through the digitalization of marketplaces and processes for agreeing on investments. A blockchain-based platform offers an innovative marketplace to link investors and project developments by digitalizing the matchmaking, investment process, and deal between parties in a decentralized fashion, with minimized intervention of intermediaries. The digitalized and automated process leads to reducing the transaction costs in the deal flow. For example, power purchase agreements, which often take time for energy producers and buyers to reach due to the lengthy and complicated process, can be automated by standardizing templates and leveraging smart contracts to enforce legal clauses related to these agreements. Section 2.3 further elaborates blockchain's application to energy financing.

In addition, blockchain-enabled distributed ledgers provide transparency and robust rule implementation for climate markets through smart contracts (World Bank 2018b). Firstly, blockchain could enhance trust among participants in climate markets by enabling the tracking and trading of emission reduction units under the carbon offset crediting mechanisms (as described in section 2.4 through a use case in China). In addition, it may improve transparency in the allocation of emission allowances to emitters participating in an emission trading programme under a cap-and-trade mechanism. Secondly, the shared ledger will address the risk of double counting of emissions reduction by improving the robust measurement, reporting and verification (MRV) of greenhouse gases, as elaborated in section 2.5 in the case study of digital MRV. MRV is the process of collecting monitored data and collating it (GIZ 2019). It can be strengthened by blockchain as a way to reduce the time and operations required for data monitoring and gathering, improve transparency, and boost the interlinkage of diverse frameworks.

Key challenges to adopting blockchain technology in the energy and climate fields

Understanding blockchain

The blockchain ecosystem is transitioning from infancy into childhood, so the underlying components are changing (and breaking) all the time. Although this is a necessary part of growth, there is no sufficient stability on which to base mission-critical processes. In addition, the technology is too complex to be easily understood by seasoned developers (let alone the general public), and thus they need to devote more time to "wrap their heads around it" to build a working prototype.

Blockchain technology often requires changes to current/traditional processes, which many incumbents in the energy and climate fields struggle to justify. Moreover, once the technology changes the traditional processes, it requires policymakers and the business sector to handle data in a correct way so that it can be entered on blockchains. It might be necessary to build the capacity of these actors to operate the changed process accurately with adequate policies and regulations.

The transaction costs for renewable energy projects are relatively high due to scale, and, coupled with the permit requirements, they make asset valuation a challenge. Renewable energy, as a long-lived infrastructure investment that carries highly uncertain futures and underlying volatility, needs to be viewed from the lens of a power purchase agreement, and the life of the asset beyond this agreement. Hence, a call option for the underlying asset class may be explored wherein, if the price of the underlying asset increases, the value or payoff of the option that gives the right to buy the asset at the strike price increases. If the underlying value of the asset is less than the strike price, then the option would not be exercised by its owner, thus limiting the downside of the option to the premium paid for it. This would provide a mitigating strategy to the investors and the energy developers.

The connectivity to major grids is hampered by the inter-operability of mini-grids with major grids. Another challenge is the complexity of legislation and the associated permits required from multiple institutions. The jurisdictional issues surrounding contracts and energy law would need to be reviewed from the approaches of distributed ledger technologies and smart contracts to drive engagement.

Environmental impact of energy consumption in the mining process

While blockchain offers an incredible number of potential use cases, it is also important to consider how much energy it requires to process a transaction based on the consensus algorithm or consensus protocol that is being used. Blockchain transactions must be based on collective validation and verification through a consensus algorithm (Zheng *et al.* 2017), which is a process to achieve agreement within a distributed system.

One of the most famous consensus algorithms (thanks to Bitcoin) is "proof of work" (Bitcoin Wiki 2020). Due to the high amount of computer power needed to make proof of work function, this algorithm has showed important disadvantages such as low performance and high energy consumption (Vukolić 2016). The mining operations on Bitcoin transactions consume more than 58 terawatt-hours of electricity per year, which is equivalent to the energy consumption of Switzerland (Baraniuk 2019).

Facing such challenges, the "proof of stake" consensus algorithm was introduced in 2011 to solve the major problems of proof of work (King and Nadal 2017). There is no competition among peers working hard to solve a puzzle in proof of stake, unlike in proof of work. Hence, proof of stake consumes much less energy than proof of work, although it still consumes considerably more energy than non-blockchain centralized systems (Sedlmeir *et al*. 2020). While proof of work and proof of stake are the two most popular consensus algorithms, others are also being developed and tested, since the cryptocurrency world is constantly evolving (with more than 5,000 cryptocurrencies in 2020) (CoinMarketCap 2020).

Different blockchain technologies and their associated consensus algorithms bring different amounts of energy consumption. Therefore, it is important to choose the right benchmark when comparing this consumption (UN 2020a). To reduce the energy consumption in blockchain transactions, "green mining" is among the solutions since it builds on the use of renewable energy sources in mining operations; meanwhile, mining hardware developers are developing more energy-efficient equipment (Climate-KIC 2018).

Computing power required for grid balancing

Decentralized energy grid systems need to overcome significant barriers with regard to managing the data of multiple actors. The electricity demand and supply need to be balanced by analysing the needs of different entities (including both consumers and producers), as with centralized generation. Such data-intensive programmes would need extremely high computational power to balance the grid, with Bitcoin and Ethereum requiring over $1 million worth of electricity and hardware costs per day to run their consensus mechanisms (Konashevych 2016; Andoni 2019).

Lack of industrial standards

Microgrids may find it difficult to survive in energy markets unless there are sector-wide standards on trading procedures and protocols embedded in the smart contract that underpins the infrastructure. The standardization of procedures and protocols would enable the integration of microgrids in energy markets as it would drive cohesion and convergence. In this context, standards for microgrids can be developed through "sandbox" models where innovative solutions can be tested under real-world scenarios. The standardized procedures and protocols would ensure the inter-operability across different trading or accreditation systems, some of which may link up microgrids and carbon-offsetting projects.

Legality of smart contracts

With transactions in energy and climate markets being shifted to a peer-to-peer system, the question arises of who will be responsible for ensuring that the transactions are settled (PwC 2016). The legal responsibility for blockchain technology is difficult to attribute; knowing who should be held accountable is often unclear and will depend on the nature of the blockchain's use (PwC 2018). In this context, regulatory and legal frameworks need to be strengthened to provide accountability and responsibility in a structured manner.

Enabling environment for applying blockchain technology in clean energy and climate issues

Cross-sectoral engagement and embedded inter-operability between current and future systems would create a conducive environment for the adoption of blockchain technology. The necessary changes include fair processing and consent in data protection and privacy, new rules for self-executing smart contracts, classification and regulation of decentralized organizations, accountability and, finally, intellectual property rights.

Regulatory changes need to be fostered through capacity-building and regulatory sandbox approaches that can embed ethical sandboxes for testing new and emerging technologies such as distributed ledger technologies and artificial intelligence that can used for testing the personal data protection, etc. No specific laws exist addressing the legal implications of distributed ledger technologies, and in this context existing regulatory frameworks will have to adapt to accommodate blockchain.

As the technology's adoption is in its infancy, regulators need to follow an agile approach, such as facilitating "sandbox programmes" to incubate frameworks that consider the speed of growth and inherent challenges that exist in transitioning to a new and fast-evolving technology. Regulatory frameworks need to be developed with a view towards standardization, to improve inter-operability.

The regulatory systems have to be designed to ensure that a global standardized approach is developed with the participation of multiple countries. For example, the Blockchain & Climate Institute is collaborating with a number of representatives of national standard bodies who are part of the International Organization for Standardization (ISO) to develop appropriate standards for renewable energy-related use cases as part of the work programme of ISO TC307, which is responsible for producing the first international standard for distributed ledger technologies (ISO 22739).

Blockchain technology is evolving faster than regulation can keep up with. On the one hand, leaving blockchain developments completely unregulated allows for breathing room and technology growth; however, it hinders standardization, interoperability with other technologies and overall adoption by a larger market. By contrast, regulating blockchain efforts too much could "suffocate" the development of new use cases, stagnate technology growth and potentially drive businesses to relocate to jurisdictions with more relaxed regulations.

The large amount of data mining and management required for a scale-up of blockchain technologies will need to be monitored and regulated, necessitating the development of new infrastructure across a range of industries. For example, small producers and prosumers of energy within a peer-to-peer network would need to have an energy supplier licence; this would need to be addressed from a regulatory perspective to enable ease of participation for the different stakeholders in energy trading.

On another aspect, energy supply has traditionally been managed by large utilities and corporations, with some link with governments in many cases; however, this will be eased due to the decentralization of energy supply (Mika and Goudz 2021). Blockchain technology contributes to opening up the power generation market to smaller entities, such as smaller companies, municipalities, cooperatives and individuals. The emergence of such prosumers would decrease the risk of monopolies in energy supply (PwC 2016).

The application of blockchain holds many positive opportunities for clean energy and in addressing climate change. In particular, it can facilitate the decarbonization and decentralization of the energy sector. However, such a transition requires a number of developments in infrastructure and poses a number of challenges. Instrumental to the adoption of blockchain within the energy sector is a sympathetic regulatory framework that addresses the key legal issues raised. The case studies in this report explore actual pilot projects to draw lessons and recommendations for scaling up blockchain's application to energy and climate change issues.

1.3 Clean energy financing with blockchain technology[5]

Traditional barriers to energy and climate financing

Significant progress has been made in renewable energy deployment in recent years, yet current clean energy financing pipelines are not big enough to achieve national energy and climate goals. According to the United Nations Development Programme (UNDP), renewable energy financing requirements to meet SDG 7 are estimated at $442-650 billion per year until 2030, compared to $263 billion in 2016 (UNDP n.d.). Gaps in renewable energy financing are particularly visible in emerging markets, including in Southeast Asia, Latin America, and parts of Africa, where clean energy pipelines fall far short of clean energy targets.

While climate finance to developing countries continues to grow, in 2018 it was still $20 billion short of the goal of mobilizing $100 billion (Organisation for Economic Co-operation and Development [OECD] 2018). There is thus a crucial need for innovative green finance solutions that incentivize both public and private sector investment in clean energy and climate projects. Blockchain is one such technology that can unlock new mechanisms to catalyse green finance (including clean energy financing) in a more transparent, cost-effective and trusted manner.

Policy risks and long project timelines are often cited as the most common barriers to clean energy financing; however, renewable energy projects face other financing challenges, including: a mismatch in the capital supply and developers' needs, high investment costs, complex frameworks and standards, and a lack of liquidity and bankable projects (table 2). The lack of standardized processes (such as differing funding operations, eligibility criteria and reporting systems), insufficient information disclosure, and inefficiencies in certification can often make it difficult for parties to collaborate towards successful financing.

Blockchain's distributed ledger technology can be used to provide improvements to these aspects by enabling renewable energy project developers, investors and purchasers to collaborate on a common platform with established international standards for due diligence and compliance.

5 This content was prepared by Lathika Chandra Mouli and Sheryl Foo (Vertech Capital).

Table 2. *Challenges of energy financing that blockchain can solve*

Use case	Description	Blockchain's application
Mismatch in capital supply and developers' needs	• Need for early-stage risk capital is mismatched with investors' risk appetite.	• Standardizes performance and financial metrics for investors to holistically assess the performance of different projects. • Automates matchmaking of investors and developers based on a pre-determined risk appetite to save parties time in negotiation.
High investment costs	• Costly to source bankable projects, particularly in hard-to-reach markets with limited foreign presence. • High transaction costs in legal fees and third-party commissions for sourcing, due diligence, etc.	• Digitizes the deal flow process and minimizes intermediaries required for transparent and traceable transactions. • Enables investors and developers to view a partners' rating and historical performance to make informed decisions. • Automates matchmaking of investors and developers based on set criteria.
Complex frameworks and standards	• Lack of standardized rules and processes, information disclosure standards, and certifications makes it difficult for parties to collaborate.	• Establishes standardized processes and information requirements for due diligence, investment and development metrics, and performance tracking.
Lack of bankable energy projects	• Lack of bankable projects due to poorly drafted power purchase agreements and lack of standardized due diligence and investment frameworks.	• Digital power purchase agreements that standardize term agreements and eliminate the need for complex legal paperwork.

Many such platforms are emerging globally, with two key functionalities: blockchain-based investment marketplaces; and digital and automated power purchase agreements.

Blockchain-based investment marketplaces

Cross-border blockchain platforms can serve as a marketplace to connect renewable energy developers and investors globally while creating standardized due diligence and collaboration tools. Smart contracts can be executed to better manage and automate deal flow while ensuring that developers are matched with investors that match their financing needs and risk appetite. Creating a decentralized marketplace where investors and developers can directly communicate, negotiate and store investment details in a transparent and secure way, without third-party intermediaries, can save significant amounts of time and money for both the developer and investor. Blockchain's immutability also reduces the chances of default through identity management and ensures that only reputed actors with a history of good transactions can be identified for a deal.

By digitizing the investment process and resulting deal, blockchain can "tokenize" renewable energy assets to enable digital issuance and trading. In this way, a digital fabric can be created where asset owners can raise investments from private/institutional investors as well as trade with individual investors in secondary markets to avoid illiquidity issues. This will provide key benefits along the asset life cycle including efficiency, smoother exchange of value, and easier investor participation and diversification.

Such a solution can serve as a market-agnostic use case to advance clean energy financing in a data-driven yet secure way. It can enable small-scale project developers to get easier access to alternative sources of capital through a wider network of investors, while incentivizing international investors to participate in a more transparent investor onboarding process to develop market size. Collaboration with public sector stakeholders could also serve as a model for further blended finance mechanisms to develop local markets.

Positive Energy is an example of a blockchain-based digital platform for small- to mid-sized renewable energy projects that connects developers with a global investor community to finance or refinance projects and increase liquidity. The platform has been able to reduce the time to finance by 50 per cent through blockchain-based asset financing, trading and management. Other start-ups such as MyBit and The Sun Exchange are using blockchain to democratize renewable energy financing through crowdfunding. MyBit helps crowdfund solar panels by distributing the ownership of each system across different investors (IRENA 2019), and The Sun Exchange enables individuals to crowdfund solar photovoltaic (PV) panels and solar cells and lease them to schools and businesses in Africa to increase energy access. Section 2.3 further elaborates the use case of The Sun Exchange.

Digital and automated power purchase agreements

Blockchain can also support clean energy financing through applications in post-development energy sales that ensure the long-term bankability of a project. Renewable energy is increasingly being purchased through power purchase agreements (PPAs), a contract usually entered into by an energy producer (such as a project developer) and an energy purchaser (such as a corporate or a state-owned utility) to regulate the sale of electricity to the purchaser by setting out payment obligations to the producer. Power purchase agreements are used to secure payment streams for renewable energy projects and are often crucial for developers to obtain the initial investment required to develop a project.

However, in many emerging markets, centralized processes for power purchase agreements can be inefficient and lengthen project timelines. Structures and standards for these agreements are also fragmented between markets, and the lack of a standard framework often results in many renewable energy projects being deemed "unbankable" if they fail to adequately protect the investor from risks such as the inability of the purchaser to pay for power or early termination of the power purchase agreement.

Two other market dynamics are changing the complexity of power purchase agreements:

- **The rise of corporate power purchase agreements to meet decarbonization targets:** There are numerous complex ways to structure corporate power purchase agreements, which tend to be more challenging than standard utility power purchase agreements due to issues including lower credit ratings of corporates, and frequent fluctuations in power demand (Baker McKenzie 2015).

- **Decreasing renewable energy subsidies:** As the cost of renewable energy drops and governments begin phasing out subsidies and feed-in tariffs, renewable energy projects will be more exposed to the fluctuations of the open market (DNV-GL 2019).

Power purchase agreement structures must evolve to account for these changing market dynamics and price fluctuations while ensuring bankability. A cross-border blockchain platform can be used to digitize a standard template and enable transparent collaboration among power producers, purchasers and investors through a shared ledger. Smart contracts can be leveraged to automate the price calculation for power purchase agreements based on market dynamics, and to automate the enforcement of key legal clauses generally required for bankable power purchase agreements, such as a "take or pay" clause, *force majeure* and reassignment of the power purchase agreement. This automation eliminates the need for third-party intermediaries, which are often costly and time consuming.

Finally, digital power purchase agreements can create a mechanism to tokenize, fractionalize and easily transfer parts of or whole power purchase agreement rights to other stakeholders in a secure and transparent way to further ensure long-term bankability.

WePower is one such platform enabling the financing of renewable energy projects by using tradable smart contracts to establish digital power purchase agreements. This platform enhances the ability of renewable energy developers to secure investors for projects and purchasers for energy. WePower's digital power purchase agreements also provide buyers with greater liquidity through a secondary power purchase agreement market, where the purchase agreement can be divided into smaller agreements to allow smaller entities to participate in a contract. WePower has existing projects in Australia, Estonia and Spain that have demonstrated savings of up to 30 per cent compared to traditional power purchase routes.

All in all, these two applications of blockchain – investment marketplace and digital power purchase agreements – can unlock new ways to finance and sustain renewable energy projects and enable markets to meet clean energy goals. As with any solution for financing, however, applications of the technology face challenges including regulatory compliance for asset transactions and market-specific requirements for renewable energy projects. Blockchain as a technology is also developing to address technical challenges such as energy consumption and scalability.

As the technology matures and as start-ups pursuing related clean energy financing applications commercialize, blockchain technology could revolutionize how the renewable energy sector finances projects – and perhaps be that missing key to meeting clean energy goals.

2. Case Studies

2.1 Reimagining the electricity trading market: Power Ledger[6]

Introduction

Power Ledger is a company based in Australia that uses blockchain technology to facilitate the trading of electricity and environmental commodities. Among Power Ledger's solutions, blockchain-based platforms for energy trading allow for renewables to be scaled with fewer inherent issues, and help retailers invent new business models to capture value. The platform enables consumers to play a significant role in making the grid future-proof, hence smoothing the uptake of distributed energy resources.

If done the right way, localized energy markets downstream of distribution sub-stations, including peer-to-peer energy trading and optimized virtual power plant technologies, provide the missing piece for scalable distributed energy resources. The net result is that, together, they make energy systems cleaner, cheaper and more resilient, thus providing the ideal solution to transforming energy markets.

Challenges of the electricity market

Electricity markets in more developed economies have changed significantly in the past 15 years as a result of increased investments in renewables and distributed energy resources. Such investments were largely driven by the era of subsidized tariffs for electricity generated through renewables, such as the feed-in tariff, resulting in the addition of renewable energy that was not "fit-for-purpose".

Electricity grids were not designed for distributed and variable generation. The mismatch between supply and demand in location and time is commonly called the "duck curve", illustrating power production over a day and showing the timing imbalance between peak demand and renewable energy production. This has led to significant and costly system stability issues, including those related to reverse flows, voltage, reactive power, grid balancing and frequency control, as well as challenges with the scheduling of baseload generation. Such issues have made both grids and the resultant energy more expensive. To overcome these obstacles, there has been a shift in both regulatory settings and energy trading technology.

Regulatory settings are shifting to encourage renewables to be located closer to the sources of demand and to promote the flexibility of renewables and energy loads. This is seen, for example, in the Australia Energy Market Commission's (AEMC) two-sided market initiative and in similar changes in the United States and Europe. Such regulatory reforms are intended to rectify the duck curve, which will facilitate the adoption of distributed energy resources in a scalable way for the grid, without a need for subsidies (US Department of Energy 2020; European Commission 2021).

These regulations will create the foundation for more dynamic pricing of grids to signal the installation of distributed energy resources near to where they are needed and supported by technology platforms to create the market conditions. This will enable local energy markets and the price signals to deliver a stable, clean and low-cost energy system.

What blockchain offers

Technological innovation within the energy trading sector is functioning to optimize the use of renewables. A blockchain-based energy trading platform is inter-operable and allows for distributed energy resources to participate in the energy market to optimize dispatchable loads and load-shifting through peer-to-peer energy trading. Blockchain technology, including smart contracting functionality, has the potential to manage complex systems in a decentralized manner that is low-cost and secure. Using blockchain empowers consumers to participate in energy markets and enables the energy market to be more efficient.

Gains in transparency, competition, cost savings and efficiency in the operation of energy systems make blockchain a key innovation addition to use price signals to more rapidly drive electrification projects in an efficient and fit-for-purpose way (Ipakchi and Albuyeh 2009; Farhangi 2010). A blockchain-based trading system will help realize various benefits in energy markets, as illustrated in table 3.

6 This content was prepared by Jemma Green, Vinod Tiwari, Vignesh PS and Annabel D. (Power Ledger).

Table 3. *The benefits blockchain brings in electricity trading markets*

Category	Description
Frictionless trades	Trade and settlement are one and the same thing. This reduces anxiety about when an entity is going to get paid.
High scalability	Blockchains can be scaled for large domains due to their decentralized nature. They can also be customized to provide tailored solutions to end users.
Mutual trust	Blockchains increase trust in transactions while being transparent, removing the need for an intermediary authority.
Verifiable records	Blockchain allows for the generation of immutable records by providing the complete output of every transaction.
Security	The information in a blockchain is stored across a network of computers rather than a single server. This changes how critical information is shared, preventing fraud and unauthorized activity.

Using these regulatory and blockchain-enabled technology approaches, developing countries can leapfrog to scalable distributed energy resources.

Box 2.

Blockchain facilitates clean energy choice by consumers

EkWateur, an electricity retailer in France, intends to address customers' interest in energy choice. The company's Vision platform, based on the Power Ledger solution, enables electricity consumers to trace and choose their own energy mix based on the type, source, location and amount consumed. For example, through the platform, consumers can see the disaggregation of how much of their demand is being supplied by hydropower and solar energy farms at any particular interval.

The platform empowers consumers who are concerned about the environment to support local clean energy projects. Such a platform can be leveraged to create a market for renewable energy and a tariff for decentralized energy systems, as it can help create demand-led price signals for the generation of particular renewables.

Case studies

Background

The case studies below draw on the design and learnings from projects in India, Thailand and Malaysia to provide insights and a blueprint for how electrification projects in developing countries can be implemented in a way to deliver security, sustainability and affordability.

Uttar Pradesh, India

In India, the government of Uttar Pradesh has introduced blockchain technology to its rooftop solar power segment. It is the only state in the country that has amended its regulatory framework to facilitate controlled peer-to-peer energy trading via Power Ledger's software.

Following regulatory shifts, Power Ledger established a pilot blockchain project, run by the India Smart Grid Forum. This was drafted by the state's power utility, Uttar Pradesh Power Corporation Limited (UPPCL) and the Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA). From this draft, a regulatory sandbox was created in the city of Lucknow to facilitate the testing of adaptive responses to market disruptions. Power Ledger's platform was then integrated with smart meter systems in Uttar Pradesh to enable households to set their own prices, track energy trading in real time and facilitate the settlement of surplus solar transactions in real time through smart contracts executed on blockchain. The regulator in Uttar Pradesh is keen on seeing the benefits of this pilot, as the state is considering moving away from net metering to lower gross feed-in tariffs.

The current sell-back price to the grid hovers at around 2 Indian rupees per kilowatt-hour (kWh), while consumers are currently procuring at 6-7 Indian rupees per kWh. This provides for an energy arbitrage opportunity that can offer better returns to prosumers and cheaper prices for consumers. The results and recommendations of the pilot project will be submitted to UPPCL and the Uttar Pradesh Electricity Regulatory Commission for consideration of framing regulations to promote the peer-to-peer trading of rooftop solar power among prosumers and consumers in the state.

Instead of relying on electricity subsidies, which are often unsustainable, peer-to-peer energy trading, enabled by secure blockchain technology, acts as a market-based incentive for the accelerated deployment of rooftop solar PV in developing countries.

T77 and TDED, Thailand

The T77 project was launched in Thailand in August 2018 with the aim of providing a market-based mechanism as an alternative to a subsidy-based or government-funded feed-in tariff. It involves peer-to-peer trading among several large energy consumers in the T77 precinct, including Habito Shopping Mall, Bangkok International Preparatory & Secondary School, Park Court Serviced Apartments and Dental Hospital Bangkok. More than 630 kilowatts of rooftop solar PV is currently installed on buildings in this precinct (figure 4), and the installation capacity, as well as the number of buildings participating in peer-to-peer energy trading, will soon be enhanced further.

Any solar energy generated by each of the participants is to be consumed within the building first, and any excess can then be sold to the other participants to offset their electricity bills, using Power Ledger's blockchain-enabled trading platform. The Metropolitan Electricity Authority has allowed access to its electricity network for the physical transaction of energy between the participants. The project promotes increased customer control over energy use and the uptake of rooftop solar and other distributed energy resources for local consumption.

Since the commencement of the project, the participating entities have realized clear, tangible benefits. On average, 10 megawatt-hours was transacted on a peer-to-peer basis per month, offering electricity that was 7.5 per cent cheaper than the grid capacity. Transactions of around 1,500 Australian dollars (around $2,000) proceeded from peer-to-peer trading each month.

A second initiative in Thailand, Power Ledger's collaboration with Thai Digital Energy Development (TDED), will see the application of blockchain technology to manage energy at four clean power projects of BCPG Group, which have been included in a "sandbox project" by Thailand's Office of Energy Regulatory Commission to accelerate renewable energy use. Through this, Power Ledger is among the pioneers in applying blockchain technology in peer-to-peer energy trading.

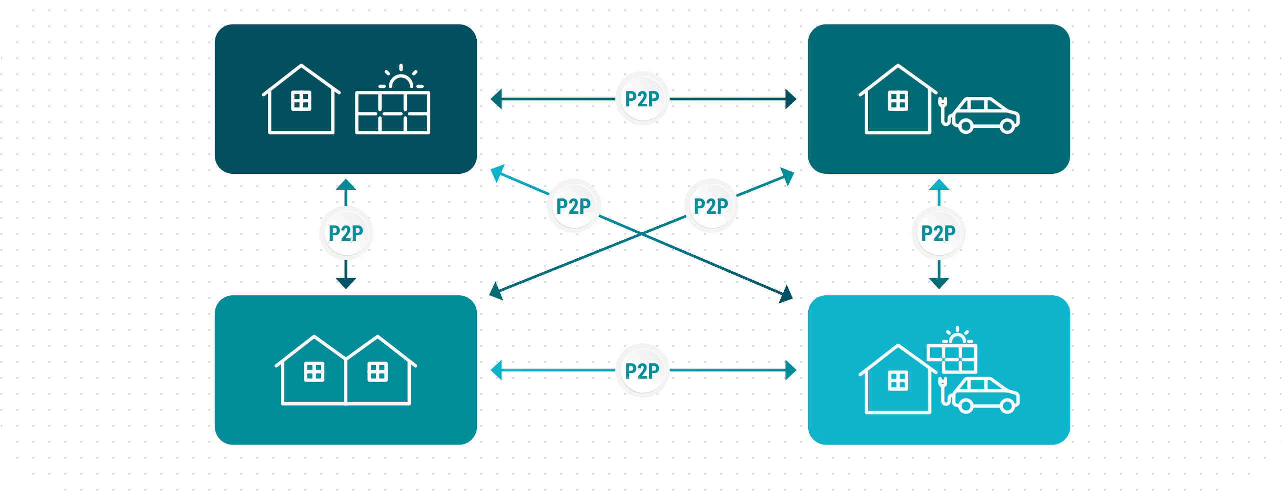
The learnings from these projects will be used by the Energy Regulatory Commission and the Thai government to set a framework for scaling up peer-to-peer power trading in Thailand. In August 2019, the Energy Ministry announced plans to promote a peer-to-peer model for private companies to decentralize the country's power generation system, in line with the new version of the Power Development Plan (PDP) for 2018-37. As one of the largest and earliest-deployed peer-to-peer projects globally, T77 has inspired energy companies and policymakers in countries like India, Japan, Malaysia and the Philippines to use peer-to-peer energy trading as a market-based mechanism to financially incentivize consumers and prosumers and to manage excess supply and demand as well as voltage and capacity constraints in the localized energy markets downstream of sub-stations.

Figure 4. T77 project site

© BCPG

SEDA National Pilot, Malaysia

Figure 5. Decentralized electricity market



In June 2020, the Sustainable Energy Development Authority (SEDA) of Malaysia and Power Ledger completed an eight-month peer-to-peer energy trading trial. The objective was to effectively trade surplus solar energy, with SEDA's goal being to grow the country's rooftop solar PV market in a scalable way, avoiding the need for curtailment and without causing issues to the grid. The project helped balance prosumers and consumers in order to prevent excess in supply and reverse flows, reducing energy costs and improving the return on investment for prosumers.

Even in the early days of evaluation, the concept of peer-to-peer trading was appealing to consumers in many ways. As in any peer-to-peer model, the concept leverages sharing economic benefits, underpinned by digital technologies, brought about by the combination of blockchain, the Internet of Things, smart contracts, big data and cloud applications.

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Policy recommendations

Based on the pilot projects run by Power Ledger, several recommendations can be made to countries that are looking to grow distributed energy resources in a scalable way, without government subsidies.

1. **Smart market mechanisms can use blockchain-facilitated technologies to improve the management of the renewable energy market**, thus removing the need for curtailment of renewable energy. By adopting techniques that make pricing structures more demand-centric or by using smart meters, the market signal is able to connect distributed energy resource assets in a way that allows them to support efficient use of renewable energy.

2. **Market rules should be revised to allow batteries and virtual power plants to participate in the market.** This will incentivize the installation of batteries that deliver network and system benefits, not just batteries facilitating self-consumption (Green, Newman and Forse 2020).

3. **Policymakers and energy market rule makers should consider transitioning feed-in tariffs towards a time-of-use model[7], or removing feed-in tariff subsidies altogether.** The Power Ledger platform eliminates the need for feed-in tariffs by creating a marketplace that efficiently regulates demand and supply. Such a shift would encourage the use of cheap solar peer-to-peer energy, when available, and could propagate load shifting and thereby support distribution networks and reverse flow issues.

4. **Remote communities that cannot be served through conventional means should be classified as microgrids.** A case-by-case approach can be used to ascertain the best practices that would be suitable for them.

7 A time-of-use feed-in tariff model is a mechanism present at different price points dependent on the time of day, that reflects the need for electricity in the system at that moment.

Box 3.

ASEAN's first trading platform for RECs

Power Ledger, along with Thai Digital Energy Development, also launched the first blockchain-enabled trading platform for renewable energy certificates (RECs) in the Association of South-East Asian Nations (ASEAN) region. This new TraceX platform is also housed at the T77 site. RECs generated with solar PV on-site, based on meter readings derived from the peer-to-peer platform, will be sold in a REC marketplace that spans Southeast Asia, with the process of issuing, trading and retiring RECs to be recorded on Power Ledger's platform.

This marketplace is Power Ledger's own platform, which can process the issuance, trade and retirement of RECs based on the International REC Standard (I-REC), the global standard for energy attribute tracking. Each REC issued by I-REC represents 1 megawatt of renewable energy. This standard is currently recognized in several countries across Asia, Africa, the Middle East and Latin America.

TraceX provides several significant benefits for developing countries, where traditionally energy trades are carried out over the counter. TraceX reduces the counterparty settlement risk, the cost to reconcile trades and the complexity for market participants (by virtue of a simplified process). It is easier to scale the market size, attaining market liquidity. The platform also enables market participation for residential and commercial rooftop solar PV, which is not currently possible in most developing countries.

2.2 Blockchain-based renewables platform: Energy Web Origin[8]

Introduction

Energy Web Foundation (EWF) is a non-profit that is developing publicly available, decentralized solutions designed specifically for the energy sector. EWF's Energy Web Origin (EW Origin) is a suite of open-source, fully customizable software tools for building blockchain platforms for easy and efficient renewable energy sourcing in line with the existing standards and regulations. To date, EW Origin has been leveraged by different energy actors to establish decentralized marketplaces for green electricity attribute certificates (EACs)[9].

Challenges of the EAC market

EAC tracking systems in developed markets such as the European Union have been operating for decades, so blockchain is by no means the only digital solution. Because EACs require a robust regulatory framework and platform for the energy attributes, however, current EAC markets in developing countries (which are mostly voluntary[10]) suffer from high administrative costs, dependence on intermediaries, distrust in the renewable energy supply, and overall complexity in meeting one's renewables targets.

It is essential to develop a transparent and accessible market that offers affordability for renewable energy project developers to participate in. Transparency of the market is also indispensable to attract buyers of the certificates. Simplification and dis-intermediation of the EAC market would help unlock the market barriers, which also improves the process of tracking and reporting the energy attributes.

What blockchain offers

These issues can be addressed by a blockchain-based EAC market platform that can increase trust, simplify investment tracking and reduce administrative costs. Specifically, blockchain application enables four unique advantages:

1. a common and trusted digital infrastructure that suits multi-party EAC markets that are highly fragmented today;
2. cost-efficiency and scalability to handle an ever-increasing number of devices and users of any size (which is currently not easily possible in EAC markets due to manual and complex processes around registration, issuance and trading);
3. excellent tracking capabilities for every step of the EAC value chain; and
4. credible data about renewable energy products, which is crucial for accurate accounting of environmental benefits and their ownership.

8 This content was prepared by Meerim Ruslanova and Doug Miller (Energy Web Foundation), with additional contributions from Supharat Ridthichai Thorne (PTT Thailand), Can Arslan (Foton), Sila Kilic (Foton) and Carlos Chávez (Mercados Eléctricos).

9 EACs are a market-based mechanism to incentivize renewable power generation and consumption. Each EAC represents proof that 1 megawatt-hour of renewable electricity has been produced or consumed. Most known EAC standards are Guarantees of Origin (GOs) in Europe, renewable energy certificates (RECs) in North America and International RECs (I-RECs) in developing markets.

10 Voluntary EAC markets refer to markets driven primarily by large corporate renewables buyers that have voluntary renewable energy targets (e.g., RE100 members; see http://www.there100.org/companies).

Building on these advantages, EWF's EW Origin is implemented (figure 6) to build blockchain-based EAC marketplaces that comply with the International Renewable Energy Certificate Standard[11] (I-REC Standard), a globally recognized EAC standard present in more than 35 countries. EW Origin's functionalities include registering users and devices, tracking renewable energy and issuing, trading and claiming corresponding I-RECs in a regulatory-compliant way due to EW Origin's full integration with the I-REC Standard, as specified in table 4.

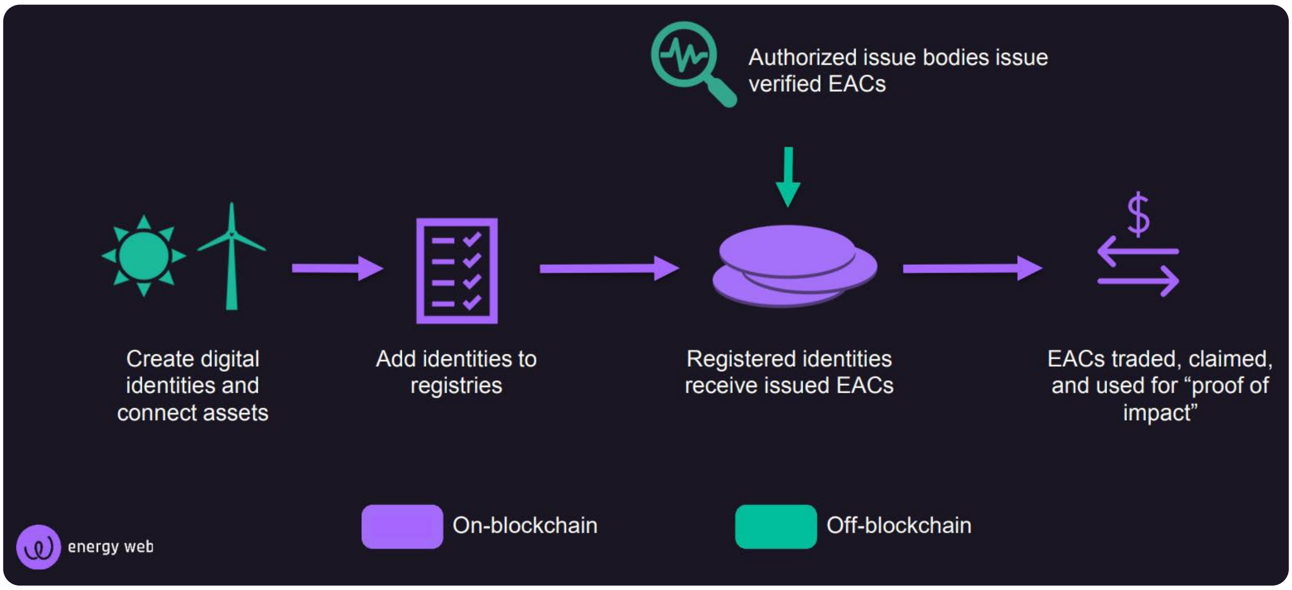
Table 4. *Functionalities of EW Origin*

Functionality	Description
Registration	Platforms powered by EW Origin allow EAC market participants (e.g., buyers, traders) to register as users and enable device owners to also register their generation assets with the I-REC Standard. This is verified by the local I-REC issuing body*.
REC issuance	Registered and verified device owners can request certificates directly via the platforms. The issuance of certificates aligned with I-REC is recorded on the blockchain to transparently track the entire life cycle of the EACs.
Trading	Platform users can post bids (demands) and offers (supplies) for I-RECs from a single energy source or a package of I-RECs (e.g., a portfolio of solar and wind). Sellers can post asks to the marketplace, while buyers can browse through the available asks and buy or create their own bids.
Claiming I-RECs	After a trade is executed, the owner of the certificates can claim and use them for sustainability reporting.

* For example, Green Certificate Company (GCC), the default I-REC issuer, fulfils the role of an issuing body fully in El Salvador and partially in Thailand; see https://gcc.re. Most of the issuance in Thailand will be taken over by EGAT, a state utility that has a partial stake in generation and full control of the transmission system operation; see https://www.irecstandard.org/news/first-i-rec-issuance-in-russia. In Turkey, Foton is a local issuing body.

Among the main beneficiaries of the platforms are: renewable energy generators that would gain access to new sources of funding; renewable energy buyers that would benefit from low-cost tools to better achieve their targets and communicate this proof of impact; and regulators that could use established voluntary markets as a reference for national tracking systems.

Figure 6. Functionalities of the Energy Web Origin open-source software toolkit



11 http://www.irecstandard.org

Case studies

Background

This section provides case studies from Turkey, Thailand and El Salvador, where EW Origin is implemented. Blockchain platforms based on EW Origin are built and operated by diverse energy actors in the respective countries. All three platforms leverage, to a different extent, EW Origin's functionalities to track and trade renewables in line with the I-REC Standard.

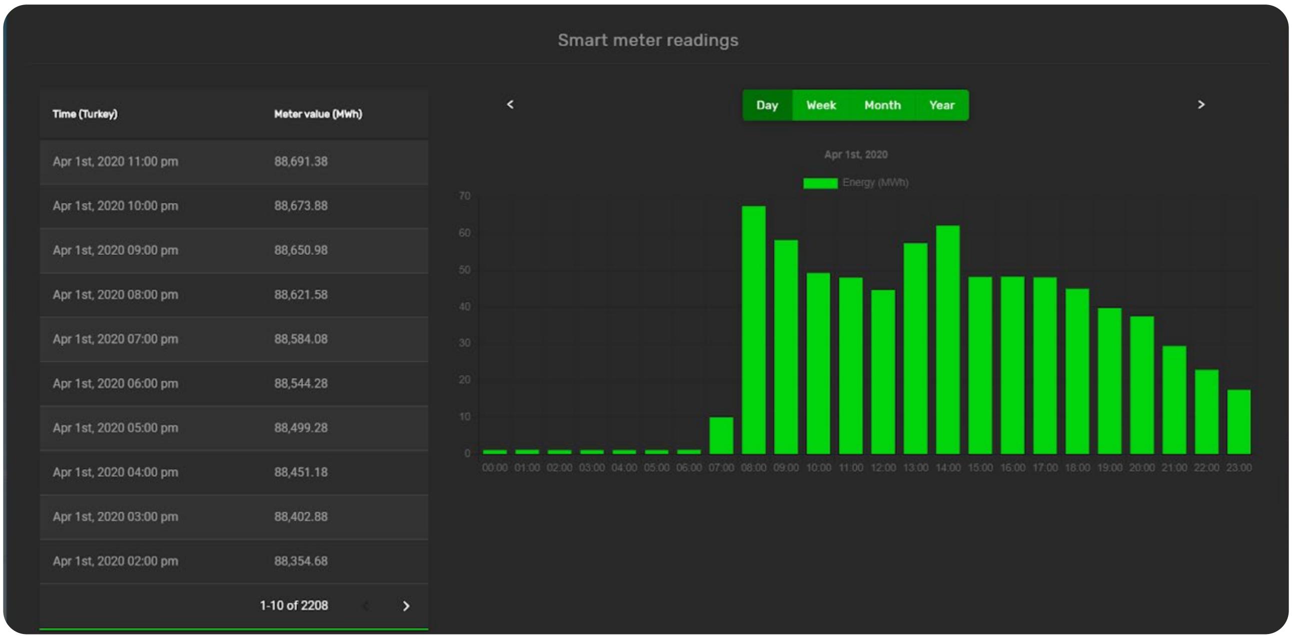
Foton in Turkey

Foton[12], a Turkish innovation company founded in the Innovation Center of Energy Exchange Istanbul[3] (EXIST) to accelerate the energy transition, is running a commercial pilot platform for I-REC trading between generators and buyers.

Turkey has a transparency platform[14] hosted by EXIST that displays the hourly generation data of licensed plants (figure 7). Since these data are easily accessible on EXIST, Foton's pilot platform integrates with EXIST to securely access accurate power generation data and improve the device certification and I-REC issuance process. Therefore, registered devices can request I-REC issuance directly via Foton's platform, which pulls information about their hourly generation data from EXIST via an application programming interface (API).

Foton's pilot platform could go one step further and enable device owners to request certificates in one click by simply defining a device and a period. They could choose to manually trigger the issuance process or even opt-in to automatically request certificates at defined time periods. This more digitized approach will streamline the issuance process, reduce human error, and decrease the time and effort needed to process an issuance request, improving the user experience dramatically. Foton is also providing active feedback on designing a mandatory tracking system for Turkish EACs to be compatible with the voluntary I-REC market.

Figure 7. Foton's pilot platform in Turkey pulls generation data from a transparency platform, EXISTReAcc in Thailand



PTT[15], Thailand's largest conglomerate with commitments to the United Nations Sustainable Development Goals and interest in low-carbon business, is launching ReAcc, the first commercial grade blockchain-based solution. The platform provides all the functionalities needed for I-REC procurement in a regulatory-compliant way.

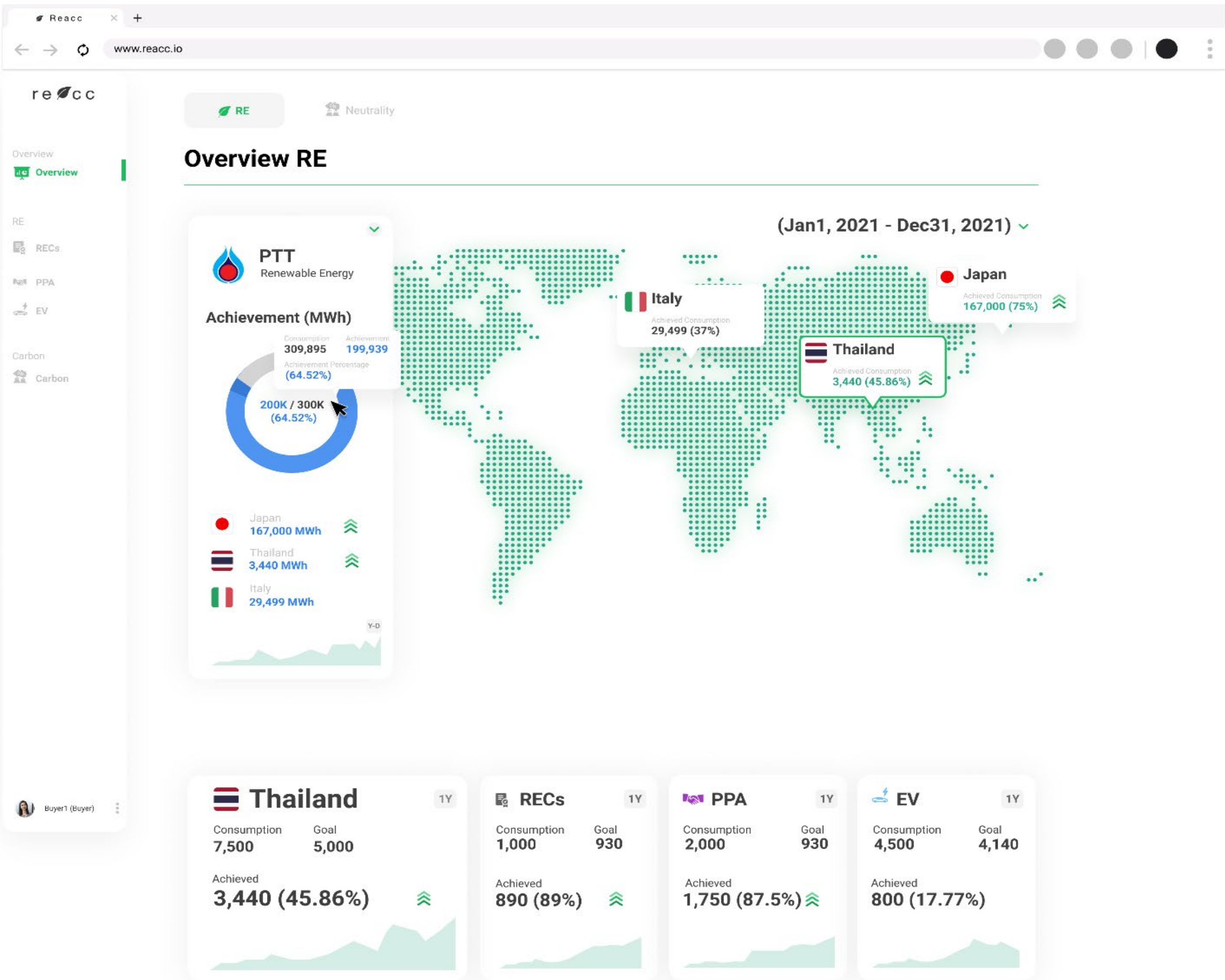
In Thailand, real-time generation data are not publicly available. ReAcc can help device owners onboard their real-time generation data via smart meters. In addition, device owners that are registered and verified by the I-REC Standard can request certificates by simply submitting generation evidence through ReAcc. The integration with the I-REC registry allows I-RECs to be issued via ReAcc upon approval from the I-REC local issuing body.

PTT also has developed special planning tools (figure 8). Sellers can manage their renewable energy generation and I-REC inventory more effectively, while buyers can input their targets and sourcing requirements and easily track their progress.

12 https://fotonenergy.com
13 https://www.europex.org/members/epias-energy-exchange-istanbul
14 https://seffaflik.epias.com.tr/transparency
15 https://www.pttplc.com/en/About.aspx

In addition, buyers are increasingly looking for EACs bundled with the purchased electricity and for projects resulting in new renewable energy capacity. Thailand's vertically integrated electricity market structure does not support these renewable energy sourcing options. Therefore, to address buyers' demand to prove impact, ReAcc is planning to introduce a feature to support renewables that have not been built yet by purchasing long-term I-RECs from new impactful projects.

Figure 8. ReAcc: Planning tools for renewable energy buyers
Note: This image is the exclusive property of PTT PLC and is protected under international copyright laws.



To scale up the solution, ReAcc will start offering I-RECs separately from electricity due to the vertically integrated energy market structure in Thailand. The platform's design, however, can support the addition of new features in the medium term, such as long-term I-REC agreements for existing and new projects and renewable energy purchases for electric fleets. PTT welcomes corporate buyers that have operations in Thailand and Southeast Asia to engage with ReAcc and provide feedback on the platform, as well as to support renewable energy in the region (figure 9).

Figure 9. ReAcc: Example of PTT Group's (CHPP and GPSC) solar farm co-locating with agricultural use of a shrimp farmer cooperative (Chanthaburi Province, Thailand)

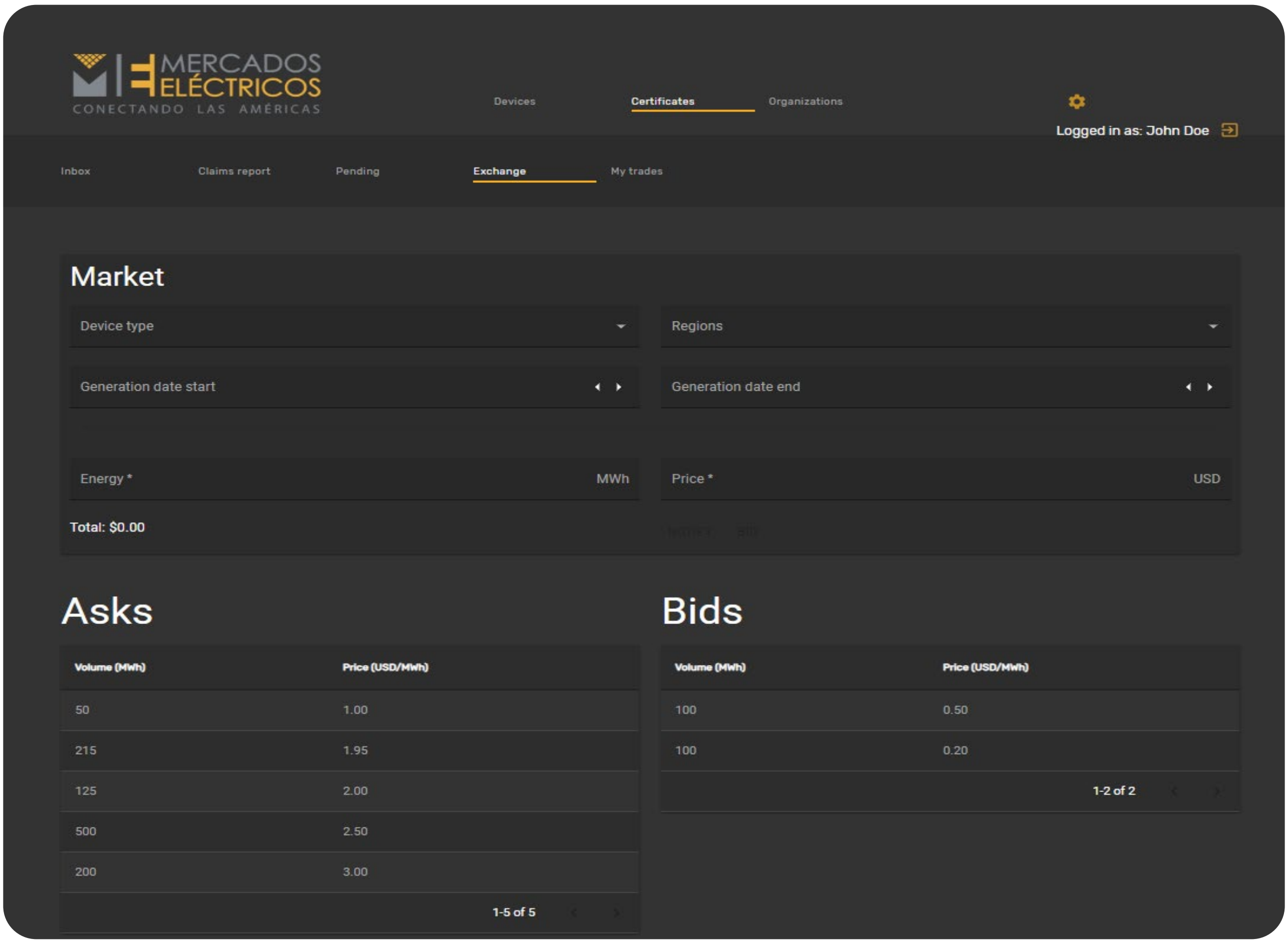
Note: This image is the exclusive property of PTT PLC and is protected under international copyright laws.

MERELEC in El Salvador

Mercados Eléctricos[16] (MERELEC), an electricity trading corporation operating across Mexico and Central America, is executing a pilot platform to assess a business case for and technical feasibility of a blockchain-based regional I-REC marketplace (figure 10). Since El Salvador did not have an I-REC market in the beginning of the pilot (2019), MERELEC successfully took the lead in establishing the I-REC Standard in the country.

Users of EW Origin can post asks and bids manually or automatically for recurring transactions. The platform matches supply and demand based on the specified criteria, and users can see their successful and pending transactions. In MERELEC's pilot, the bids are matched based on the lowest price. Once the bid is matched, a buyer is able to see the successful transaction in their inbox.

Figure 10. MerElec: I-REC marketplace in El Salvador



MERELEC's pilot platform intends to become a one-stop-shop for multinational companies with a footprint across Central America and not just in El Salvador. In the near future, up to 200 devices in El Salvador are planned to be added to this pilot platform. Moreover, MERELEC is seeking more corporate renewable energy buyers to test, inform and improve the pilot platform, as well as funding partners interested in further scaling the platform. Once mature, the regional I-REC market can serve as a foundation for establishing a regional tracking system for energy products, similar to the Guarantees of Origin (GO) system in the European Union.

However, rolling out these platforms has not been without obstacles. Some of the challenges include data acquisition, inexperience with the technology and untapped demand for I-RECs, as elaborated in table 5.

16 https://www.mercadoselectricos.com.sv

Table 5. *Challenges and coping strategies related to blockchain platforms*

Category	Description
Generation data acquisition	A secure connection of renewable energy plants to the platforms is important to ensure accurate data flow. Given the diversity of generation devices, there is no harmonized data acquisition system. To address this issue, EWF has designed an API service that allows anyone to integrate their generation data source independently from the data collection methodology.
Inexperience with the new technology	To increase awareness about blockchain, project partners are organizing workshops about decentralized technologies for relevant stakeholders and working on technical features to make the user experience with blockchain platforms simple and intuitive.
Untapped demand for I-RECs	Since I-REC markets in all three countries are voluntary, it is important to increase buyer participation. Hence, platforms are designed to accommodate even the smallest buyers (e.g., public institutions, small and medium enterprises) and an efficient price discovery mechanism.

Policy recommendations

These examples illustrate how market participants can successfully leverage and customize existing public blockchain technologies in different countries to streamline renewable energy markets and encourage standardization. Moreover, the blockchain platforms in the three countries can be used to incentivize renewable energy investment. Lessons and recommendations include the following:

1. **Blockchain platforms can be leveraged to create an alternative revenue stream of renewable energy projects in the post feed-in tariff era.** Both Thailand and Turkey have been showing significant success in deploying renewables with the help of feed-in tariffs. However, feed-in tariff rates decreased or will decrease dramatically in both countries, which leaves renewable energy developers seeking new revenue sources to stay competitive with conventional power plants.

2. **All three countries' I-REC sales constitute an attractive revenue stream for generators and a credible sourcing option for renewable energy buyers.** As illustrated in this section, El Salvador, trying to use its vast untapped renewables to decrease expensive fossil imports, does not have a mandatory tracking system and abundant financial incentives for renewable energy producers. Unlike Thailand and Turkey, however, El Salvador is a small market, but the country is part of the Central American regional power system. Since most countries in the region already comply with the I-REC Standard, Central America presents an opportunity for establishing a regional I-REC market.

3. **Collaboration is key to developing policies and regulations that steer innovative digital climate solutions.** The experience from Turkey, Thailand and El Salvador offers recommendations to regulators in developing countries with regard to innovative technologies such as blockchain. In general, regulators are encouraged to provide active feedback, via joint workshops or interviews, for instance, to ensure that solutions meet energy market requirements and complement policy goals. It is also important to ensure public support of applications that reinforce policy objectives, such as government buildings participating in pilots where they act as renewables buyers on the local platforms. Use of the sandbox is also recommended, to experiment with the use of blockchain in safe and flexible environments. When it comes to technology selection, open-source technology can ensure continuous improvement over time as more market participants use and enhance the solutions, and helps regulators and market participants avoid lock-in of technology service providers.

2.3 Financing solar energy through blockchain: The Sun Exchange[17]

Introduction

The Sun Exchange is a micro-leasing marketplace that connects investors, both individuals and companies, with the beneficiaries of solar installations in rural South Africa. Recognizing that the main obstacle to the deployment of solar energy in Africa is the lack of financing for businesses and organizations, and that blockchain and cryptoassets are a class of technologies that allow money to be easily transferred around the world without financial intermediaries and at negligible cost, The Sun Exchange platform was founded in South Africa in November 2015, by Abe Cambridge and his team.

Challenges of clean energy access in Africa

In Africa, biomass and hydropower resources are more abundant in the humid, southern and central regions of the continent, and wind energy is very present in the eastern and northern regions of the continent. However, the sun is omnipresent. Even so, the continent, which has the world's largest solar resource, has

17 This content was prepared by Jacques-André Fines Schlumberger (Blockchain for Good).

installed only 5 gigawatts of solar PV, less than 1 per cent of the world total. In sub-Saharan Africa, only 28 per cent of health facilities have reliable electricity, two-thirds of schools have no reliable electricity, and distance learning is unimaginable.

However, with more than 300 days of sunshine per year and falling technology costs, the International Energy Agency predicts that by 2040, solar PV will surpass hydropower and natural gas in installed capacity to become the continent's largest source of electricity (International Energy Agency 2019). Mini-grids could play a critical role in providing electricity to rural communities and local businesses.

What blockchain offers

Blockchain technology has the potential to address failures in financial markets – particularly in emerging and developing economies – by establishing trust and reducing transaction costs. Its application is particularly interesting for the millions of "unbanked" people. Blockchain-based financing platforms enable distributing and receiving funds in digital currency from various investors – such as individuals, corporates and foundations – to the recipients, while increasing transparency. This is because blockchain helps trace the origin, destination and application of the resource. The platforms also enable reducing the costs associated with multi-layered reporting through self-auditability of blockchain.

Such platforms can play a useful role in introducing renewable energy that is suited to the needs and the capacity to pay of the rural poor. Blockchain-based financing offers enhanced efficiency and transparency of the climate finance flow, which eventually increases trust between beneficiaries and investors.

Case study

The Sun Exchange platform in South Africa

The Sun Exchange platform allows anyone with an internet connection to buy solar panels online and rent them to businesses, hospitals, schools and other organizations based in Africa, with the promise of a 10 per cent return on a 20-year contract. The Sun Exchange platform organizes the process of collecting and distributing monthly rentals through Bitcoin or local currency. The platform uses the Bitcoin blockchain for cross-border payments so that there are no intermediaries between the beneficiaries of the installation who pay for their electricity and the investors who participated in the purchase of the solar panels.

Between January and November 2015, The Sun Exchange installed the prototype of the first solar power plant at a school in the Cape Town region, financed entirely by private individuals in cryptocurrencies. Three years later, The Sun Exchange had more than 6,000 registered users and had completed its seventh solar power plant. Between September 2018 and September 2020, the platform grew from 6,000 to 18,000 users in 162 countries and from 7 to 31 solar installations, with a total electrical capacity of 3.6 megawatts.

A solar project is set up in the following manner: A team of engineers from The Sun Exchange company evaluates, with local construction companies, the technical and economic feasibility as well as the social and environmental impacts of a solar project. Once the project is ready to be funded, it is published on the crowdselling platform, where anyone can register and buy solar cells – at the cost of 50 South African rand ($4) per cell. Once all the solar cells are sold, the local partner carries out the construction work, which takes an average of four to six weeks.

The solar panels are connected to The Sun Exchange platform through smart contracts using Internet of Things sensors. Once the solar installations are operational, the beneficiary pays to consume the electricity produced by the cells, and the owners of the solar panel receive every month the amount corresponding to their investment, in the form of rents net of insurance and service charges, paid in local currency or Bitcoin.

The beneficiaries include schools, retirement homes, small and medium-sized businesses, nature parks, non-profit associations and other organizations that cannot afford the initial investment of a solar installation. Through The Sun Exchange's solar installations, these organizations have reduced their energy costs by 20-30 per cent and have been able to redirect these funds towards their core offerings, including providing quality education for children, positive living environments for elderly residents and care for vulnerable wildlife. In 2019, projects in schools and retirement homes benefited some 5,500 learners and 150 elderly people.

Figure 11. A solar-powered school in South Africa

© The Sun Exchange

The Sun Exchange platform has also launched the SUNEX token sale. SUNEX is a loyalty rewards token that customers can use to increase their purchasing and earnings power on the platform. SUNEX tokens are distributed on the Ethereum blockchain through a smart contract. SUNEX token holders can obtain a range of financial and practical benefits on the platform of The Sun Exchange, including discounts on all future solar cell purchases, increased lease payments from solar cells, early options to buy into new projects and opportunities to vote on future project crowd sales. The SUNEX token is also being staked to create a Solar Project Insurance Fund, SPIF, to cover the costs of relocating solar plants to new sites if the original power purchasers default on their payment obligations, and up to 20 per cent return is paid in SUNEX.

In June 2020, The Sun Exchange raised $3 million from the Africa Renewable Power Fund of London's ARCH Emerging Markets Partners, closing a $4 million Series A financing round. The funds will be used primarily to expand into other sub-Saharan African countries, with the first project, outside South Africa, announced in the fourth quarter of 2020 and involving a major agricultural enterprise (The Sun Exchange 2020).

For The Sun Exchange platform to continue, the cost of solar PV electricity must be lower than the cost of electricity from fossil fuels or carbon-intensive energy. Lower technological costs have led to a drastic drop in the price of solar electricity. According to BloombergNEF's 2019 *New Energy Outlook*, the cost of solar modules has fallen by 89 per cent since 2010 and will fall a further 34 per cent by 2030 (BloombergNEF 2019). In addition, blockchain and cryptocurrencies make impact finance possible through frictionless cross-border payments that bypass costly financial intermediaries between micro-investors and the beneficiaries of solar projects through smart contracts.

Policy recommendations

A blockchain-based platform allows individual and corporate energy investors to buy solar cells that supply power to businesses and organizations in sunny emerging markets, and earn from the clean electricity generated. Enhanced efficiency and transparency are assured in energy and climate finance flows. Lessons and recommendations include the following:

1. **Policies and regulations should prepare the enabling environment for digital solutions.** In its journey to success, The Sun Exchange has not encountered any political or regulatory barriers, as the size of solar PV installations remains within the required limits of utility projects. The regulatory limit set in South Africa is 10 megawatts, while the largest installation created by The Sun Exchange is 0.5 megawatts. The company is even supported by the government, especially in South Africa's Western Cape province, where The Sun Exchange supplies energy to 13 schools with the support of the province's Department of Education.

2. **Policies should support maximizing the benefits from innovative solutions.** The next challenge is to optimize these grids and to lower the cost for beneficiaries by selling excess production to the main electricity providers. Already, South Africa's local and national governments have developed the necessary rules and regulations for non-utility-scale solar installations. However, excess solar power generated through The Sun Exchange's projects is fed into grids at a loss, negatively impacting project economics. This situation will improve when South Africa's government allows the purchase of this excess solar power by the main electricity providers, thus creating a bi-directional electricity grid that includes local solar power production.

With its cost-effective collaborative model, backed by a mix of Internet of Things and blockchain technologies, The Sun Exchange provides affordable green electricity that fits the market for rural communities. Through its projects, the company has taken the opportunity to provide education on renewable energy, together with raising awareness about sustainability and climate change mitigation. Other countries may learn from this business model to scale up clean energy financing in those areas where electricity is not yet supplied.

2.4 Blockchain-based carbon credit trading platform: ECO2 Ledger[18]

Introduction

ECO2 Ledger, a public blockchain programmed by Synergy Blockchain Technology and overseen by the ECO2 Foundation, has been developed within the context of the international voluntary carbon market. It aims to improve the operational efficiency of carbon credit trading and to stimulate climate actions from individuals and private and public sector organizations through a blockchain-based platform.

Challenges in voluntary carbon markets

At present, several inefficiencies exist within the voluntary carbon market. Firstly, carbon markets are structured in a multi-centralized fashion, meaning that markets of various jurisdictions are usually not interlinked and lack connections between objective and independent systems that are open and transparent. This structure creates high operation and maintenance costs, making it difficult to promote carbon markets as an emission reduction solution.

Furthermore, the regulations for carbon markets are complex and issued from multiple centralized bodies that do not always act in unison. There are many restrictions and thresholds for transactions within carbon markets, over-the-counter trading procedures are complicated and slow, and carbon assets have relatively low liquidity.

18 This content was prepared by Nick Manthey and Neo Lin (ECO2 Ledger).

In addition, accounts within carbon markets are not designed for individuals and lack transparency. Many carbon markets do not allow individuals to open accounts or have high financial thresholds for opening accounts. The current account system is a restrictive one that limits the disclosure of information to the public and is only available to carbon market participants – a model that is not conducive to the advancement of global emission reductions.

Lastly, the development process for an emission reduction project is lengthy and slow, taking around 30 months to move from initial conception to final credit issuance. Moreover, there are large upfront expenses for application fees or payments for third-party verification, resulting in significant sums of initial investment. Therefore, only large-scale emission reduction projects are economically viable, reducing the likelihood of smaller projects from entering the market.

What blockchain offers

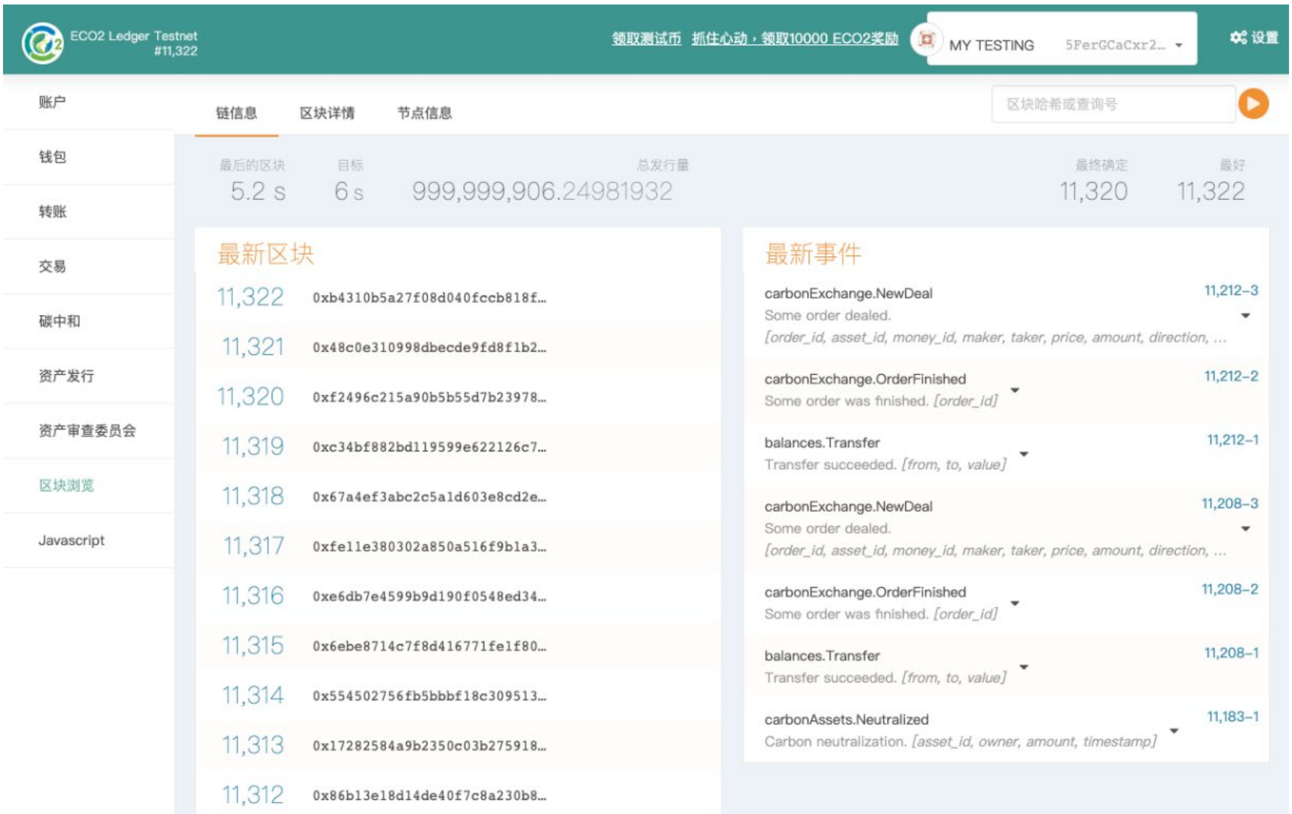
Blockchain technology can be leveraged to establish an emission reduction consensus in accordance with the goals of international climate change treaties or the Paris Agreement. The inherent properties of blockchain technology make data transparent, provide tamper resistance and prevent double counting. These properties can be utilized to enhance carbon markets by making carbon credit data more reliable and traceable, improving trading efficiency and market regulation, and reducing the costs of carbon credit validation, carbon credit transactions, market entry and market operation. Through their innovative platform architecture, blockchain-based carbon credit trading systems can increase liquidity, broaden participation in global carbon emission reduction and increase levels of carbon neutrality.

Case study

ECO2 Ledger in China

ECO2 Ledger has been designed to allow participants in the voluntary carbon market to issue and trade their carbon credits on a blockchain-based platform (figure 12), linking with individual buyers who are looking for ways to achieve carbon neutrality. The benefits of ECO2 Ledger are two-fold. Firstly, the carbon credits that circulate on the platform are currently sourced from emission reduction projects in China that are verified according to the Verified Carbon Standard (VCS). When users or nodes in the ECO2 Ledger network consume carbon credits, they are providing demand for offsets that benefit local communities in China, such as in poor rural regions that are transitioning to more sustainability-oriented economies such as improved forest management and ecotourism. At present, any VCS or Gold Standard carbon credit can be tokenized on ECO2 Ledger, bringing benefits to the local communities of those projects in other developing countries.

Figure 12. *ECO2 Ledger Testnet*
© ECO2 Ledger



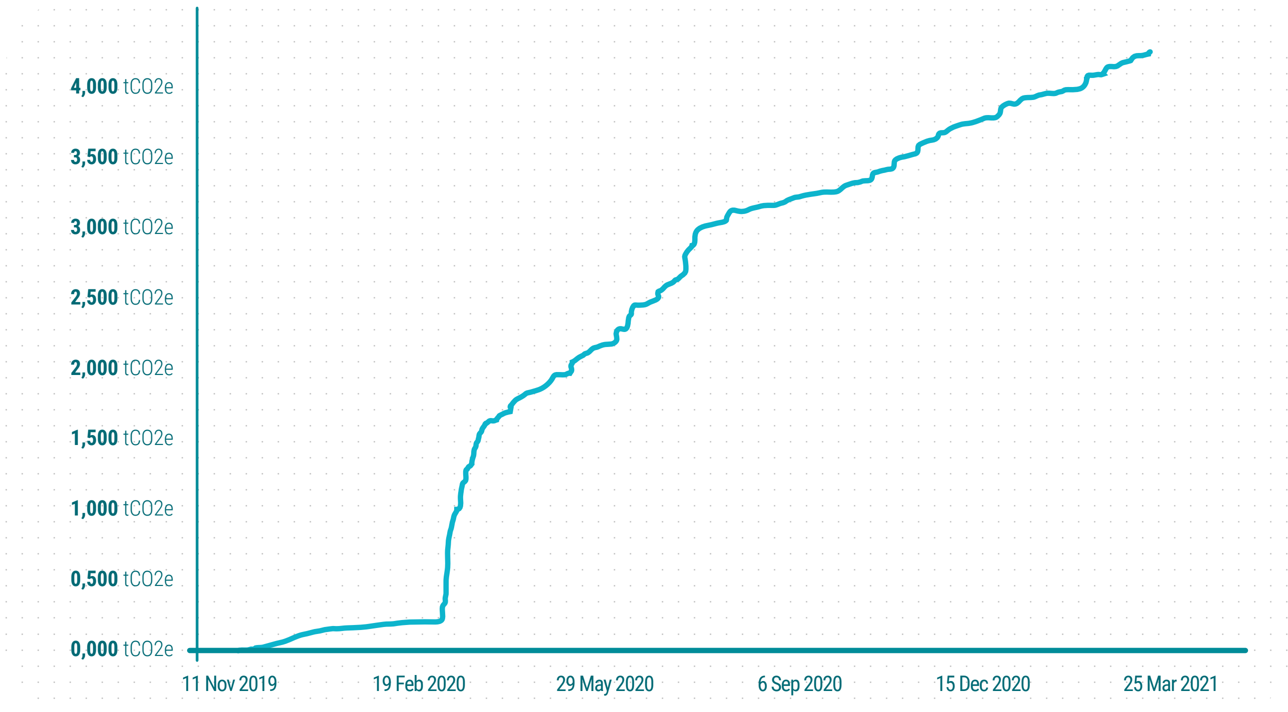
The second benefit is creating incentives for users on ECO2 Ledger to engage in climate action. This is done by rewarding users for participating in the governance and operation of the platform, which comes in the form of digital token rewards. As all of the transactions on ECO2 Ledger will be offset by carbon credits on-chain, users are indirectly contributing to climate action through their activity on ECO2 Ledger and are in addition rewarded for their carbon neutrality.

Unlike the traditional carbon credit registries, ECO2 Ledger will allow individual users to have free and open access to their own carbon accounts, stimulating climate action at the individual level. To promote the concept of individual carbon accounting and offsetting, the MyCarbon app was developed alongside ECO2 Ledger (figure 13). On MyCarbon, basic gaming features incentivize users to learn more about climate change and carbon trading. Since its launch, MyCarbon has registered nearly half a million users and has more than 60,000 daily active users on average.

MyCarbon's users also have the ability to estimate and offset their personal carbon emissions. For example, between 14 November 2019 and 26 March 2021, users offset 4,253 tons of CO_2-equivalent emissions (figure 14). After the launch of ECO2 Ledger's main net, offset data from MyCarbon will be publicly recorded on ECO2 Ledger, allowing anyone to view and share their carbon neutral actions. As blockchain technology continues to mature, further integration between MyCarbon and ECO2 Ledger is planned. Due to MyCarbon's growing popularity, grassroot communities that are enthusiastic about blockchain and sustainable development have emerged in several major cities in China.

Figure 13. *MyCarbon mobile app*
© ECO2 Ledger

Figure 14. Total amount of carbon offsetting through MyCarbon
Source: Author calculation



However, blockchain technology continues to have a considerable environmental impact through its energy consumption and carbon footprint, mostly related to the proof of work algorithm and the cryptocurrency mining industry (see section 1.2). For this reason, ECO2 Ledger has been designed to be completely carbon-neutral by making carbon offsetting a core feature of its design. Transaction fees on ECO2 Ledger are pooled in a publicly viewable address and used to purchase verifiable carbon offsets to maintain the carbon neutrality of the network. Thus, ECO2 Ledger's blockchain architecture allows it to be a net zero carbon emission technology specifically designed for international carbon trading.

Although blockchain is a regulated industry in China, political and regulatory barriers have not posed a significant challenge for the development of ECO2 Ledger. Throughout its development timeline, ECO2 Ledger's developers have been transparent with the relevant blockchain regulatory bodies of China, such as the Ministry of Industry and Information Technology, the China Communications Industry Association's Blockchain Specialized Committee, as well as the Ministry of Ecology and Environment. Given China's blockchain and climate change goals, ECO2 Ledger has received positive feedback from government officials during its development. However, when scaling up ECO2 Ledger to other countries and regions, uncertainty exists with respect to the legal conditions of securities and money transmission and other regulations such as tax and data privacy. Facing such complexities, policy guidance at the international level may help address the diffusion of innovative solutions across countries.

Several challenges exist to scaling up the solution (table 6). Within the context of China, knowledge barriers regarding climate change and market-based solutions still exist. Although the concepts of environmental awareness and sustainability are on the rise in China, they have yet to be realized on a large scale with respect to individual emission reductions. This has been a barrier to expanding the domestic user base of ECO2 Ledger, which is designed for individual participation in offsetting and carbon neutrality. However, as China's carbon markets mature, and as other actors in the private sector develop products that incentivize personal carbon accounting, this knowledge barrier is expected to weaken in the short term.

Clarity around blockchain-based solutions for carbon trading is also still lacking within the emissions trading industry. Because ECO2 Ledger is designed for enterprises and organizations in the emission trading industry, this lack of certainty on the value of blockchain technology has served as a barrier to increasing private sector and non-profit participation in the ECO2 Ledger ecosystem. A majority of companies and organizations have heard of blockchain technology but still lack experience using blockchains or digital token wallets, and many would like to see more regulatory approval of these technologies before getting further involved.

Table 6. *Challenges to scaling up a blockchain-based carbon credit trading platform*

Category	Description
Knowledge barriers	Knowledge barriers around climate change and market-based solutions still exist among the industry and general public. In addition, industry players need clarity about blockchain-based solutions for carbon trading to participate in the market mechanism powered by blockchain.
Legal and regulatory uncertainties	Complexities of securities law, money transmission law, tax regulations, privacy and data ownership, and various other jurisdictional restrictions and prohibitions exist and need to be addressed.
Policy guidance at the international level	There are still a lack of frameworks, guidelines, specifications, and best practices for blockchain applications designed for climate action or other Sustainable Development Goals, which may lead to a lack of inter-operability among blockchain solutions for climate issues.

To scale up or replicate a use case such as ECO2 Ledger in another region, acquiring users and building international partnerships are crucial. The success of MyCarbon in China, as elaborated above, can be built on when expanding ECO2 Ledger in another country and region. In addition, team members at ECO2 Ledger have been active in several international organizations focused on blockchain and climate change, such as the Climate Chain Coalition and the International Association of Trusted Blockchain Applications (INATBA).

Policy recommendations

ECO2 Ledger is one of several blockchain projects around the world that are seeking to mitigate the effects of climate change, as articulated in the Paris Agreement and represented by SDG 13 on Climate Action. Lessons and recommendations from the experiences discussed in this section include the following:

1. **There are still a lack of frameworks, guidelines, specifications and best practices for blockchain applications designed for climate action (or other SDGs),** although ECO2 Ledger collaborates with other projects and organizations that have similar goals. While some organizations, such as the Climate Chain Coalition and INATBA, are attempting to define and support such policies, it would be helpful for policymakers to craft their own recommendations in order to standardize the development of blockchain technology for SDGs.

2. **Failing to streamline such policies could have implications for future blockchain-based systems, which could suffer from a lack of inter-operability.** Policy areas to consider include climate data, climate modelling projections, sectoral impacts, asset-based risks, metrics, finance, and digital Measurement, Reporting and Verification (MRV). Furthermore, guidelines regarding blockchain data structures, token standards, and even recommendations on the legal nature of tokenized carbon credits would help accelerate the implementation of blockchain projects. Complexities of securities law, money transmission law, tax regulations, privacy and data ownership, and various other jurisdictional restrictions and prohibitions regarding blockchain technology still exist and ought to be clarified through policies that support digital innovation for sustainable development.

3. **Blockchain for climate action is not a "winner-take-all" application area.** If blockchain technology is going to truly reduce global emissions, then multiple platforms and protocols must work together to digitize and govern the various segments of climate action, including finance, markets, certification, registries and raw climate data. International and inter-industry cooperation and collaboration are essential to create global blockchain-based infrastructure that not only accounts for the multiple facets of climate action, but also remains flexible to anticipate and incorporate the benefits of rapidly developing emerging technologies.

2.5 Digital MRV in a waste-to-energy project in Chile[19]

Introduction

In order to meet the Paris Agreement's goal of limiting the increase in global mean temperature to well-below 2 degrees Celsius above pre-industrial levels, all countries will need to implement measures to mitigate their greenhouse gas emissions. To advance this global effort, the Government of Canada is providing support to developing countries to help them implement their Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement. One such initiative aims to help Chile reduce greenhouse gas emissions in its waste sector (Climate Ledger Initiative [CLI] 2019).

The Canada-Chile Reciclo Orgánicos Program is a partnership of the governments of Canada and Chile as well as private sector partners such as Arcadis, ImplementaSur and ClimateCHECK. It includes mitigation measures such as the commissioning of a modern landfill gas capture and destruction system at the Copiulemu landfill to cost-effectively reduce greenhouse gas emissions. The programme has also developed standardized measurement, reporting and verification (MRV) methodologies (i.e., "protocols") to quantify the emission reductions achieved by these mitigation measures.

Challenges in traditional MRV systems

Standardized methodologies, such as in the Western Climate Initiative that administers emission trading markets between the Canadian province of Quebec and the US state of California, are a key feature of a credible MRV system. They allow for the generation of comparable emission reductions as "mitigation outcomes" that are quantified and verified according to a transparent process. However, these methodologies are most commonly implemented through activities that have relatively high transaction costs, involving highly manual data collection, reporting and verification processes. This includes on-site observations, gathering of data files, spreadsheet calculations, and the engagement of a third-party verifier to verify greenhouse gas emission reductions.

Various opportunities exist for improving these methodologies. They include, but are not limited to: reducing the timeline for MRV activities, improving the transparency of provenance, and improving the consistency and cohesiveness between recorded mitigations outcomes on NDC registries and climate finance reports from an MRV system perspective (this is especially important in the context of the Paris Agreement).

What blockchain offers

A variety of new digital solutions to address the challenges and opportunities noted above are being tested around the world on various types of climate actions, such as forestry, supply chains, and renewable power; these generally are referred to as "digital MRV[20]" (CLI 2019).

19 This content was prepared by Tom Baumann (Climate CHECK) with additional contributions from Mathew Yarger and Florian Doebler (IOTA).
20 Descriptions of "digital MRV" are presented in Baumann (2020) and Halubouski (2020).

By increasing the trust and transparency in the system, the digital MRV pilot, led jointly by IOTA[21] and ClimateCHECK[22] and resulting in the digital MRV solution branded as DigitalMRV™, is enabling new applications for greenhouse gas MRV based on the advantages of distributed ledger technologies in combination with Internet of Things digital sensors and secure structured-data transmission into the distributed ledger technology that feeds the online reporting and verification. To make full use of their potential to advance MRV, the pilot is built on permissionless ledgers in order to ensure the sustainability and scalability of the digital MRV solution based on an open ecosystem.

Case study

Digital MRV pilot in Reciclo Orgánicos, Chile

The digital MRV pilot in the Canada-Chile Reciclo Orgánicos Program started in January 2020 and continued to March 2021. The first stage of the pilot assessed the landfill gas site's (figure 15) monitoring system/plan and data systems (e.g., landfill gas collection volumetric flow rates, gas composition analysis, combustion device and operation, combustion efficiency) as well as other relevant information systems (e.g., back-end capabilities, data availability and data quality assurance / quality control (QA/QC), Internet of Things digital device connectivity, security, external data sources). In parallel with the assessment of project information and creating a plan ("design specification") to build the digital MRV solution, the Chile landfill gas MRV methodology developed for Reciclo Orgánicos with the support of ClimateCHECK was integrated into the digital MRV solution to automate the procedures.

Figure 15. Copiulemu Landfill Gas Facility

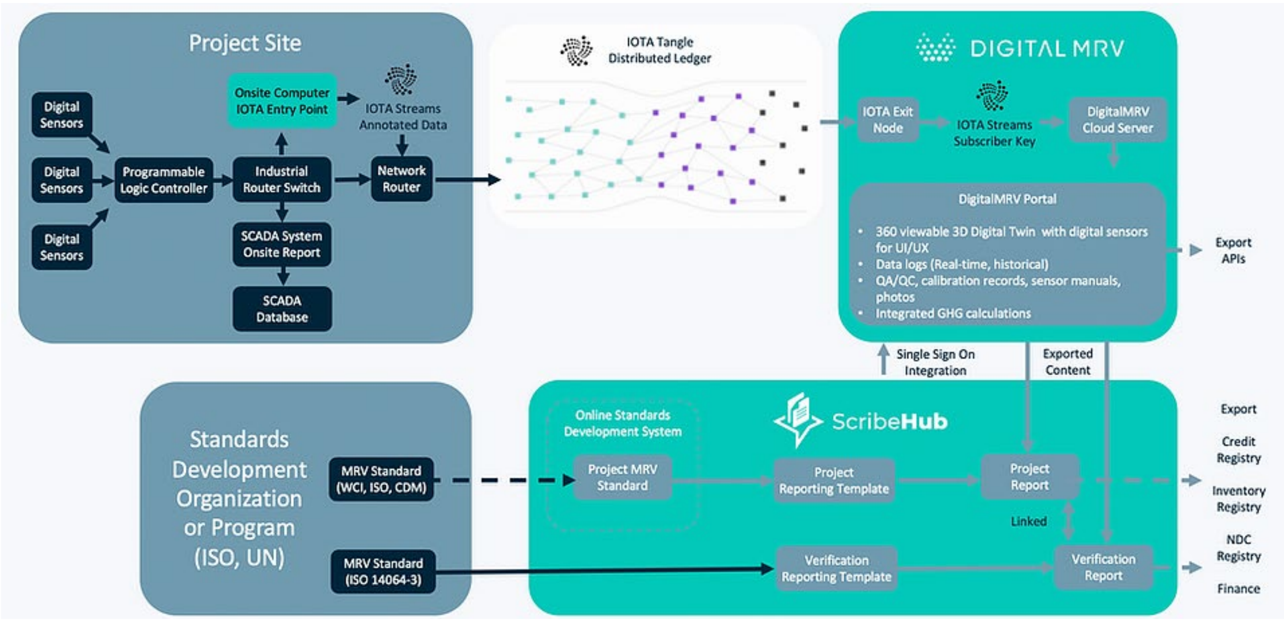
© Environment and Climate Change Canada

21 www.iota.org
22 www.climate-check.com

The digital MRV solution incorporates the specifications from the digitized MRV methodology and links together the on-site Internet of Things devices and data flows with the distributed ledger technology-enabled platform using the IOTA Tangle and ScribeHub for online greenhouse gas MRV, as illustrated in figure 16. Structured data collected via digital sensors (Internet of Things) and secured in distributed ledger technologies in combination with digitized MRV methodologies increases the trust and utility of the data to support more efficient and effective decision-making and solutions for climate and sustainability.

After consideration of other blockchain / distributed ledger technology options, IOTA was chosen due to its many unique features, which were ideally aligned with the requirements of the pilot and to support the digitization of an MRV system of all climate actions. IOTA's features are used to create a number of unique capabilities: tamper-proof data, lightweight scalable infrastructure, removal of risk of vendor lock-in, a high level of transparency, and no built-in fees to use the network, which could cause future bottlenecks for growth. Unlike most blockchain solutions that consume huge amounts of energy with corresponding greenhouse gas emissions (CleanCoin n.d.; Digiconomist n.d.; Ghosh and Das 2019), IOTA is a sustainable, energy-efficient design, with the energy consumption for an IOTA transaction estimated to be 10 per cent less than the energy used for a credit card transaction (Markus 2019; Sori 2019).

Figure 16. High-level schematic of the DigitalMRV™ solution for the pilot in Reciclo Orgánicos, Chile



These unique abilities enabled the project to structure the data as close to the sensors as possible while providing near-real-time access to the data from the landfill gas facility. Its immutability also creates a transparent and trustable historical record of the data on a granular level, which is a major benefit for auditing sites remotely. As the project grows, these data will also be used to tie the impact that facilities are making to their environment through the generation of tokenized carbon credits enabled directly through IOTA's core functionalities. This provides strong incentives for use through a measurable, verifiable and scalable method for progressing environmental impact initiatives globally.

Following the trial and validation phase, the digital MRV solution will continue to be refined and extended for other climate action MRV requirements. The project will also support capacity-building of local partners to continue or replicate the digital MRV solution for landfill gas projects after the pilot ends.

Policy recommendations

Whereas this pilot project focuses specifically on the digital MRV for the mitigation outcomes of the landfill gas capture and destruction, the project partners will explore the future potential in other types of projects, such as bio-digestion, as well as expanding the application of digital solutions to support MRV and climate action accounting more broadly. Digital MRV is being implemented at another waste-to-energy plant in Chile that produces biogas for heat and electricity, as well as by-products for the agriculture sector.

Examples of a wider landfill gas application could include using digital solutions to: 1) link the greenhouse gas emissions inventory of the landfill reported to the national inventory and the emission reduction mitigation outcomes (whether capture and flare or capture and utilization downstream); 2) link the digital MRV of mitigation outcomes with a carbon credit registry and an online carbon credit marketplace; and 3) track and MRV climate finance associated with various climate actions (CLI 2019)[23].

Other lessons and recommendations from the experiences discussed in this section include the following:

1. **Continued developments of digital MRV in individual sector climate actions, including energy, transport, industry, agriculture and others, are essential to bring key learnings on the way to scaling up the solution.** DigitalMRV™ has the potential to be applied to other sectors beyond the scope of this pilot case study. This is important because climate change mitigation efforts range across broader types of climate actions such as low-carbon supply chains, communities, and facilities, as well as economic sectors beyond energy, including transport, industry, agriculture and other sectors. Experiments in pilot projects for other sectors would bring key learnings on the way to equip DigitalMRV™ in individual sectors and projects.

2. **In addition to blockchain / distributed ledger technologies, the Internet of Things plays an essential role in enabling DigitalMRV™**. Although Internet of Things unit costs continue to decrease and associated digital sensors are becoming more common in new-build climate actions, in some cases (such as retrofitting non-digital sensors) there are additional costs to set up a digital MRV environment that is equipped with distributed ledger technologies and Internet of Things devices with sensors. However, digital MRV solutions can save on the costs of conventional MRV, such as travel and time for an auditor to go out to a site. In addition, it requires a certain degree of digital literacy and infrastructure to operate the digital MRV, which might not be available for some types and locations of climate actions.

3. **It is critical to strengthen MRV frameworks and supporting systems in countries to fully make use of digital solutions for MRV.** In addition to the benefits of digital MRV to improve the accuracy and efficiency of greenhouse gas emissions tracking and reporting, the integration of Internet of Things digital sensors also enables data infrastructure and marketplaces to support better climate finance investment decision-making and tracking.

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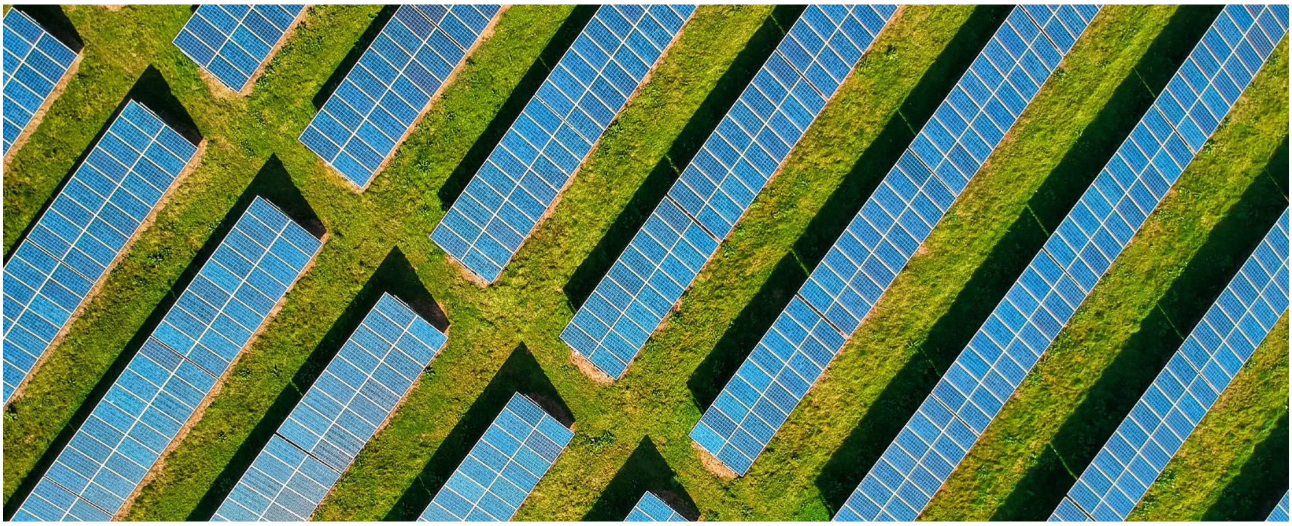
23 Learn more at https://www.reciclorganicos.com

3. Scaling Up Blockchain Application



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3.1 Road map for integration[24]

Closing the loop in climate financing and accounting

Large technological disruptions, such as cars replacing horse carriages, have been driven by new innovations whose economics produce affordable and exponential adoptions from multiple actors across supply chains (Seba 2014). The result is an economy-wide socio-technical transition that changes the fundamental paradigm between people and machines. The clean energy disruption is no exception. However, a unique aspect of the current climate and energy transition is that the ultimate driver is not coming from the innovations themselves; rather, it is from the imminent, planetary-scale environmental collapse. For the first time in human history, it is the finite nature of our Earth system that is forcing us to transform our economy and infrastructure across the globe towards a low-carbon alternative.

To achieve the climate transition at the scale and speed needed, we must ensure that all system dynamics – linking elements such as climate finance, action, value creation and policy – are aligned in reinforcing feedback loops. This means that more of one thing influences more of something else, linking a chain of action-reaction elements to unleash exponential change (Sterman 2002). Managing these complex systemic processes at a global scale is challenging. However, a second unique aspect of the climate transition is that we may have the tools to do precisely this. This is because the most recent technological disruption, the digital disruption, has produced tools that can help us influence how dynamic global systems connect.

In particular, distributed ledger technologies can directly help link systemic feedback loops. They can do so by helping to establish consensus on digital records across large networks and by allowing these records to execute causal effects through "if-then" statements in smart contracts (Wainstein 2019a). The challenge is to build a global digital infrastructure with an integrated system designed to meet net zero goals.

So far, this report has covered the role that distributed ledger technologies such as blockchain can have in innovating decentralized energy management, climate finance and carbon management. This chapter focuses on how we must leverage the technology to weave together these aspects into a cohesive system that radically accelerates the clean energy transition. In simple terms, more financial capital needs to flow towards on-the-ground climate action, producing tangible climate value that needs to translate into robust climate records. Robust climate action records, such as mitigation outcomes, should trigger more capital flow. Figure 17 shows this process using a system dynamics feedback loop.

The following sections describe how technology in network platforms can automate the connections between these core elements. Clean energy finance, with a focus on solar power, will be used as a main example.

24 This content was prepared by Martin Wainstein (Open Earth Foundation).

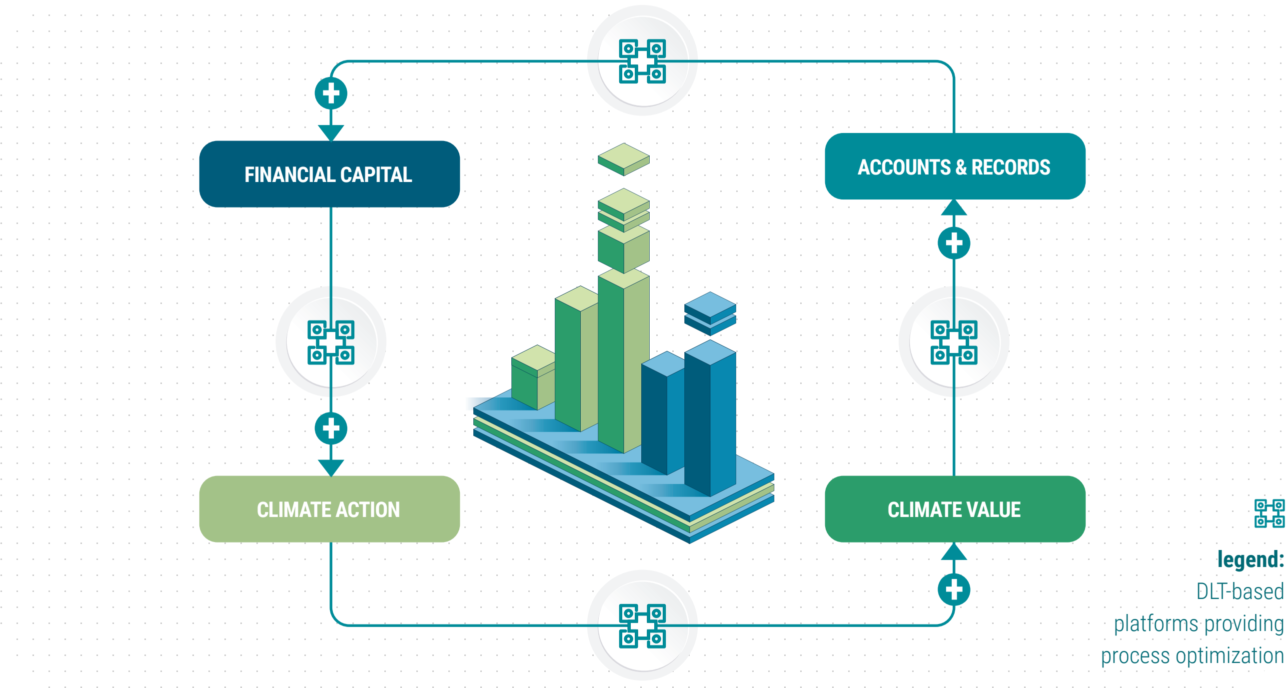


Figure 17. Closing the loop to link financial capital with accounted climate action and value

Linking bottom-up climate action with top-down financial instruments such as climate bonds

To ensure a sustainable flow between financial capital and climate actions, such as solar energy deployment, two main processes need to connect. The first is to ensure that there is a steady pipeline of investable projects across a broad spectrum, from decentralized small-scale community projects to large utility-scale projects. The second is for large institutional investors to mobilize capital into portfolios that include that broad project spectrum. This allows investors to ensure heterogeneity in project typologies and to hedge their position by diversifying risk. Technology platforms that allow these two processes to link are open investment marketplaces. Blockchain, through cryptocurrencies and contractual automation, can be leveraged by such digital platforms to remove frictions and allow complex marketplace interactions to scale without compromising trust.

Based on this layout, three main opportunities exist for digital platforms. Figure 18 provides a visual representation of where these platforms lay within the system. The first one, which we can call "origination engines", are designed to empower virtually any community member to be a climate action entrepreneur. They can do this by simplifying the origination process that translates an opportunity, such as a potential site for solar energy deployment, into a securitized investable project ready to issue a public offering.

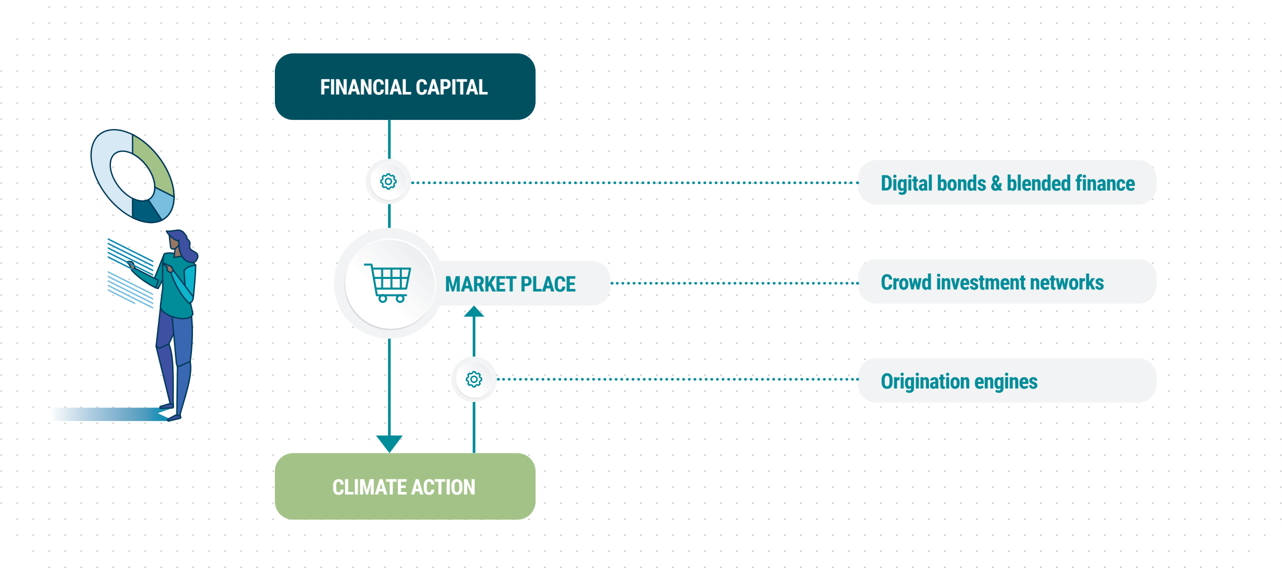
The origination process for securitized projects requires robust feasibility assessments and high legal and bureaucratic upfront costs. However, these complex financial offerings can be significantly democratized by creating digital templates of the legal processes using smart contracts, providing cryptographic trust on the underlying mathematical models that simulate a project's performance (e.g., solar financial models) and embedding the process on intuitive user interfaces. A concrete example of a solar energy origination engine using common business data standards was launched by Raise Green[25], a regulated investment portal (Raise Green 2020).

With a diverse group of the local community engaged in climate action, and ensuring that platforms are designed to local context and capacity, a country or region can ensure a steady pipeline of investable projects, leveraging collective intelligence and creating green jobs. But rather than having to seek out investors individually, project developers can use marketplaces – one-stop-shop portals where registered investors (local and international alike) can select projects that meet their impact, risk and financial return requirements. If the digital records corresponding to the project profile are properly tabulated by the origination engines, then marketplaces can provide project transparency to investors as well as valuable network effects such as reputation scores. In the United States, for example, Republic[26] uses blockchain in the context of a financially regulated investment marketplace that allows non-traditional investors to invest in securitized projects (Republic 2020).

25 https://oe.raisegreen.com
26 https://republic.co

To truly scale financial capital flows, large investors cannot be expected to review each individual project. This is where public sector climate commitment and central banks can provide support by issuing climate bonds, which can be leveraged to underwrite the pipeline of projects that meet specific quality criteria (Marke 2018). According to a report from the Sustainable Digital Finance Alliance (2019), the end-to-end digitalization and blockchain automation of climate bonds can lead to a 10-times cost reduction throughout the full life cycle of the bond (SDFA 2019). To meet this value proposition, Evercity[27], an impact-tracking blockchain company, has launched an open-source project for climate bonds using "web3" distributed ledger technology, or decentralized applications that are running on the blockchain (Evercity 2020). Once a successfully digitized bond process is templatized, it can be replicated in other jurisdictions with slight adjustments, thus falling under the Paris Agreement's technology transfer rules. This is particularly relevant for enhanced North-South and South-South cooperation to help less-developed nations that could roll out financial instruments that can boost their economy by supporting community-scale projects.

Figure 18. Digital platforms linking bottom-up climate action with large-scale financial capital



Driving climate action value through improved digital business models

The previous section described how digitization and automation can help both democratize climate action across communities (creating new developer jobs) and mobilize capital through sophisticated financial instruments and marketplaces. However, once a project is funded and built, developers or project originators need to operate the project through a prolonged time period, which introduces significant operating and maintenance costs. In the case of securitized solar projects, for example, a developer may need to operate a solar project anywhere from 5 to 20 years, managing the project's legal corporate structure (often termed a "special purpose vehicle").

A solar project company requires managing yearly legal compliance, tracking power purchase agreement contracts, submitting invoices to its electricity off-takers, processing operation and management costs, issuing and selling renewable energy certificates, and processing a capitalization table to provide dividends back to its investors. Historically, securitized solar projects have only been eligible for economies of scale where installations are over 10 megawatts in capacity. A digital platform that allows contractual, compliance and payment automation into its business process can allow securitized project as small as 20 to 50 kilowatts. To help with the solarization of the island of Puerto Rico after Hurricane Maria destroyed the centralized grid, Yale University and the Massachusetts Institute of Technology (MIT) launched the Open Solar project to accomplish this level of digital automation in solar projects (Wainstein 2019b).

Once securitized climate action projects are deployed, there may be opportunities for joined operations that can further increase the collective value of projects (figure 19). In the solar and smart grid example, this directly translated to aggregating decentralized energy resources (e.g., solar, batteries and electric vehicles) into microgrids or virtual power plants. Here again, a different digital platform can provide automation for managing a higher level of complexity, which includes electricity market trading, arbitrage optimization for batteries, and grid services that provide higher grid resilience. Blockchain platforms can help drive business models for a participatory smart grid (Wainstein 2019c).

27 https://evercity.io

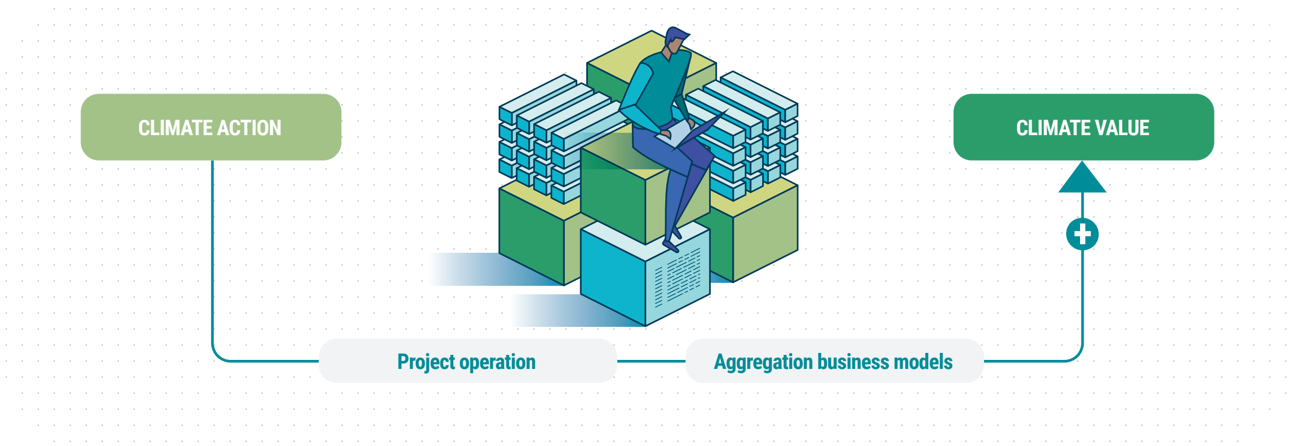


Figure 19. Digital platform opportunities to streamline deployed climate action projects

Digital MRV and nested accounting to link action records back to financial capital

Once financed climate action projects are deployed and operating, measuring and quantifying their climate value is the essential next step – whether it is quantifying their mitigation or adaptation value. Independently verifying and certifying the projects by third parties has historically been a cumbersome and costly process. However, several digital technologies can now be leveraged to significantly reduce these costs and streamline the MRV process. The use of Internet of Things sensors, satellite data and artificial intelligence all play a role in integrating real-time data streams into trusted blockchain records. The records attesting to the underlying climate value creation can be digitally audited by approved actors and turned into unique certified assets, which can be traded or retired without the risk of double counting (World Bank 2018b). In the solar energy space, this digitalization process is already transforming the process of issuing renewable energy certificates (RECs) with platforms such as the Energy Web Foundation[28] or Cleartrace.io[29].

Units like RECs or mitigation outcomes (i.e., Paris Agreement mitigation outcomes) can be traded across jurisdictions (subject to country approvals) but eventually should be retired and accounted by a specific actor, either the project developer or the buyer of units. Most project developers and carbon credit buyers are private actors rather than public entities. However, the Paris Agreement applies exclusively to sovereign nations (i.e., the Parties to the agreement), not private actors. Its accounting process requires countries to present their emissions and mitigations records vis-à-vis their Nationally Determined Contribution (NDC) in a mechanism called the Global Stock Take. To directly include all private sector climate actions and units in the Paris Agreement, their credits should roll-up to the country level and become part of the national greenhouse gas inventory.

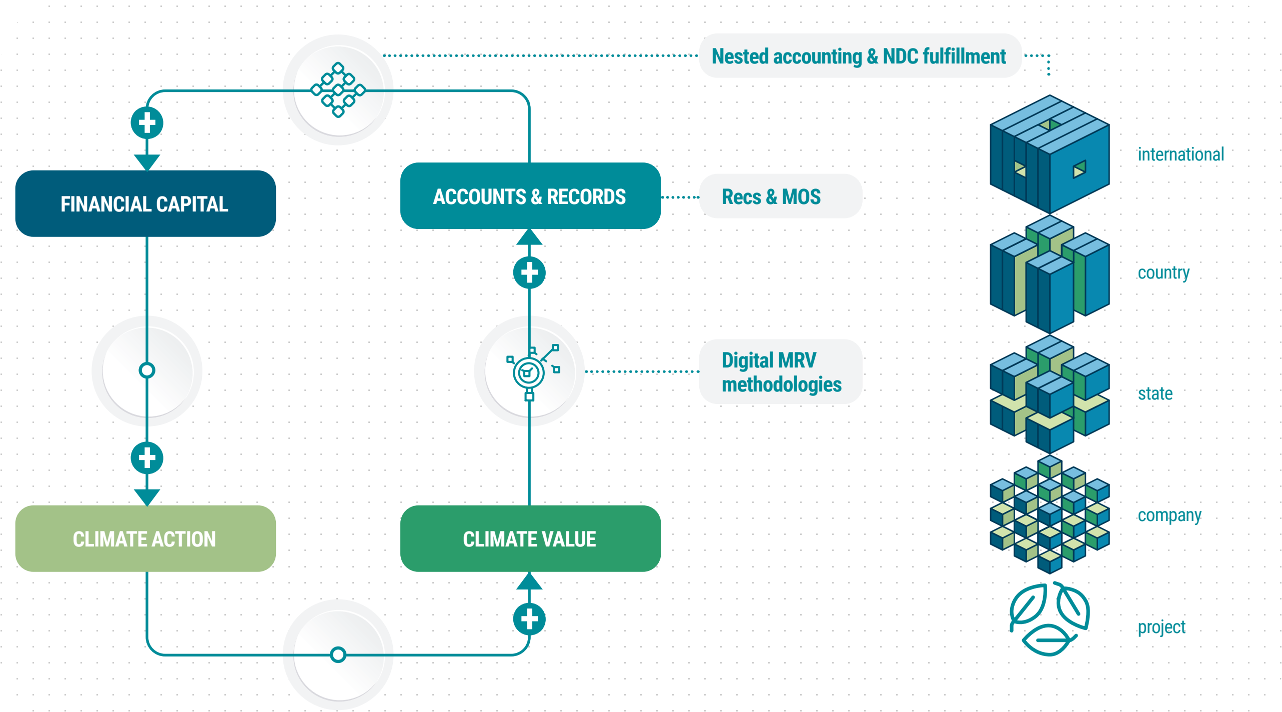
To seamlessly integrate climate data from non-state actors (i.e., private firms, cities and provincial governments) with state-level accounting, the Yale Open Innovation Lab has focused on establishing a framework defined as nested accounting[30] (Wainstein 2019b). This involves geographically tagging all climate action data and units in the context of spatially nested jurisdictions. By leveraging the architecture of a spatial web (Cook *et al.* 2020), this allows that once a unit is retired (i.e., removed from the market) a spatial contract identifies and accounts the unit to all relevant jurisdictions – all the way up to the national and international level. Each jurisdiction, defined by its geographic polygon, becomes a registry by default, not necessarily using a conventional database, but rather by queries of actions within the geographic space.

Figure 20 illustrates the nested accounting process whereby the data from non-state actors roll-up to the national context. This process also helps close the loop from the accounted actions back to the source of financial capital. Private investors, which may or may not acquire the carbon unit as part of their investment, receive a certification of impact but also ensure that the impacts are included in the international Paris Agreement efforts. From the lens of a central bank – which, for example, may have provided issuance and liquidity to climate bonds that financed solar energy deployment – this process ensures that the sovereign nation's funds are used to both create local green jobs and directly contribute to the country's fulfilment of the NDC.

Through a constellation of digital platforms that provide automation via linked records and rules, we can envision a road map where system dynamics, linking climate finance and accounting, unleash the exponential actions and change needed to undergo a full socio-technical transformation to address the climate crisis.

28 https://www.energyweb.org
29 https://swytch.io
30 https://openlab.yale.edu/open-climate

Figure 20. Linking climate value back to financial capital through digital MRV and nested jurisdiction accounting of climate credits



3.2 Considerations on ways ahead[31]

The case studies in this report illustrate how blockchain technology is being used to accelerate the development of decentralized energy systems, energy and climate financing, and digital climate solutions. While a larger number of blockchain applications in the energy sector exists for developed countries, pilot projects also are increasing and ongoing in low- to middle-income countries.

Nevertheless, the case studies have pointed to remaining challenges to fully considering blockchain technology as a solution to addressing clean energy and the climate crisis globally. Such challenges include digital literacy, data governance, technological development, policy and regulatory concerns. Building on the information shared so far, this section explores the key challenges of blockchain application and their implications for further scaling up blockchain for energy and climate issues.

Local capacity

As suggested in section 2.5, the lack of digital literacy and capacity among enterprises and the public sector delays leveraging blockchain for sustainable development. The main local capacity issues can be summarized as: lack of awareness of the blockchain potential, and insufficient digital skills (UN 2017).

Local entrepreneurs and the public sector are not usually aware of the potential application of blockchain and other digital technologies to sustainable development. To bridge this gap, it is essential to identify opportunities for progressively leveraging blockchain along with other technologies, and to assess the suitability and costs and benefits of addressing sustainable development challenges. Secondly, while there are internationally leading enterprises deploying blockchain solutions, local enterprises generally do not have the capacity to build on blockchain. Specific skills must be created/improved, especially in developing countries. The current low level of digital literacy complicates the use of devices and software to run blockchain solutions in developing countries (Global Environment Facility [GEF] 2019). This raises concerns about the loss of specialist knowledge on contracting processes and the loss of skills, which could lead to resistance in applying the technology for actual business operations.

To tackle these challenges in developing countries, innovation business hubs have been taking up the role of building the capacities of local entrepreneurs and enterprises on blockchain, via trainings and business advice. Among other topics, sustainable development is one area being targeted in such activities.

BitHub Africa is an illustration of this scenario. This commercial blockchain accelerator empowers blockchain start-ups and young entrepreneurs in Kenya through advisories and consultation workshops, focusing on financial and energy access across Africa. It sees a challenge in skill development of blockchains and other engineering of innovative technologies. Because education and training opportunities can improve these skills, BitHub Africa provides targeted training programmes and virtual courses at an affordable price through the Melanin Academy.

31 This content was prepared by Toyo Kawabata, Minang Acharya and Jonathas De Mello (UNEP).

Collaboration is also crucial to raise awareness and capacity of blockchain technology. A Hackathon that was co-organized with the United Nations Human Settlement Programme (UN-Habitat) in 2017 helped young entrepreneurs and start-ups raise awareness of blockchain, artificial intelligence, the Internet of Things and other digital solutions[32]. Additionally, the Indonesian Blockchain Association, in collaboration with the Bank of Central Asia, drew together various local stakeholders including the private sector and the government to organize a hackathon event in 2019 where 2,000 blockchain solution ideas were proposed by participants[33].

As such, technology-oriented innovation hubs in countries can steer social learning to nurture the local capacity and help identify local sustainability challenges where blockchain digital technologies can be translated into solutions. Notably, securing inclusivity would be important so that local communities, of all genders, can benefit from such efforts made by the hubs.

Data governance

Data governance, including collection, storage and ownership, is key to fostering digitalization. When using blockchain systems, the data input determines the data quality on the blockchains (Schletz, Franke and Salomo 2020). It is important to ensure that a sufficient volume of qualified data is used in the blockchain applied in the energy and climate change domain, because blockchain in itself does nothing to improve the reliability of the inputs. To run an electricity grid, various data such as historic electricity demand, outputs from renewables and weather-related data need to be taken into consideration. The process of data collection, analysis and reporting in the climate change domain involves many sources, compiling information from multiple entities including government agencies, sub-national governments and non-state actors (de la Torre *et al.* 2018).

One of the challenges in developing countries is the lack of necessary data collection systems that can be integrated into blockchain systems. Improving the system of relevant data collection is a pre-requisite to leveraging blockchain to address challenges of environmental sustainability, as blockchain can enhance trust by improving the transparency and immutability of data transactions and records. Blockchain technology does not, per se, solve the challenge of gathering data, since it aims at managing information, data and value (Schmidt and Sandner 2017). Hence, ensuring ample qualified data that can be used in blockchain-powered systems is essential.

Digital infrastructure

Driving the penetration of blockchain and relevant emergent technologies requires improving the digital infrastructure, as suggested in sections 2.2 and 2.5. Digital infrastructure improvement ranges from fundamental developments in internet access to the devices that enable the implementation of blockchain solutions.

Internet access is one of the digital rights that is among the basic human rights in the internet era (UN 2011). Such access is a prerequisite in applying digital technologies to development agendas. Although internet access is expanding rapidly, 53 per cent of people in developing countries and 81 per cent of people in the least-developed countries (LDCs) are not online (International Telecommunication Union [ITU] 2019). The price of internet access also matters. The Broadband Commission for Sustainable Development targets making entry-level broadband services affordable in developing countries, meaning that it corresponds to less than 2 per cent of monthly gross national income per capita. However, in more than 80 developing countries, 5 gigabytes of fixed broadband and 1.5 gigabytes of mobile broadband costs more than 2 per cent of gross national income per capita. The provision of higher-speed internet, the availability of good Internet bandwidth and qualified service is also behind in developing countries (ITU 2017; ITU 2019; UN 2021b).

Additionally, digitization in relevant domains with adequate devices is a prerequisite, including the use of smart meters, sensors and all corresponding standardization (Teufel, Sentic and Barmet 2019). Ideally, data collection processes on the blockchains should be automated, rather than manual, data inputs to ensure accuracy and security. This process requires not only blockchain technology but also sensor networks and relevant technologies that can automatically collect the data. This challenge exists in many developing countries due to limited access to enabling technologies, in addition to a lack of qualified data (GEF 2019). The development of use cases in vernacular language applications, focused on solving local needs for scaling up the adoption of solutions, is also vital (Mittal 2019). Governing bodies responsible for establishing the digital infrastructure are expected to play an important role to bring digital technology to infrastructure management. It would also be important to support adequate organizational and technological infrastructure to apply the emergent technologies in developed countries (OECD 2019).

Technological evolution

While blockchain can propose decentralized solutions to address sustainable development challenges, maintaining immutable networks on blockchains limits the scale and speed of transaction processing (Brody 2018). Blockchain networks copy a single transaction to all nodes in the network. This requires a huge lead time to record the transactions on blockchains. Whereas Bitcoin's network is restricted to a sustained rate of 7 transactions per second, Ethereum supports roughly 20 transactions per second because of a hard-coded limit on computation per block (Ge *et al.* 2017; Climate-KIC 2018).

This is challenging to energy and climate change blockchain applications, as these require a large number of transactions. Speedy recording of transactions is essential when a blockchain-based energy trading system is deployed at a larger scale.

32 Based on an interview with John Wainaina Karanja from the BitHub Africa and Melanin Ventures on 5 August 2020.
33 Based on an interview with Pandu Sastrowardoyo and Jean-Daniel Gauthier from the Indonesia Blockchain Association on 28 August 2020.

This issue can be resolved by limiting the degree of decentralization of a blockchain network. Permissionless blockchain basically accompanies full decentralization, but permissioned blockchain makes it possible to reduce the redundancy of networks by identifying a limited number of participants in the blockchain networks.

Permissioned blockchains are based on particular consensus mechanisms such as proof of stake and proof of authority, which consume less energy because they limit the access to blockchain networks only to permitted participants. Permissioned systems sacrifice the decentralized nature of blockchain, since blockchains can generally have only two of the following three properties: scalability, decentralization and security (resulting in a trilemma in blockchain) (European Union 2019; Pederson, Risius and Beck 2019). Hence, solution developers need to consider which aspects should be fully leveraged in relevant solutions, which end up with giving up some key benefit of blockchains. Or, we could expect further technological development that will address this trilemma, as blockchain technology is still evolving.

In addition, as argued in section 1.2, blockchain's negative impact on the environment, such as the increase in energy consumption and electronic waste, has to be addressed when applying the technology as scale. Using alternative consensus algorithms instead of proof of work is one idea, but more comprehensive and solid solutions to minimize the negative environmental impacts are indispensable. In April 2021, the Energy Web Foundation, RMI and the Alliance for Innovative Regulations announced the launch of the Crypto Climate Accord, a private sector-led initiative focused on decarbonizing the cryptocurrency industry, supported by over 45 organizations.

All in all, blockchain technology, or distributed ledger technology, itself needs to evolve to be applied to fostering environmental sustainability at scale. While technology developers undoubtedly play a key role in this, transnational digital transformation fora also may combine forces to ensure "sustainable" evolution of the technology. Such fora can include the public-private consortium that fosters dialogue among technology developers, policymakers and civil society organizations. In the energy and climate domain, the Climate Chain Coalition and the International Association of Trusted Blockchain Applications (INATBA), among others, could be the fora that facilitate such dialogues.

Box 4.

Spaces for exchanging blockchain use cases and opportunities

To follow up on an evolving technology such as blockchain, different fora are being established to engage public and private stakeholders in discussing use cases and assessing the adjustment and creation of policies and regulations. Below is a list of a few platforms designed to spark collective insights and foster knowledge on the recommendations on soft-rules and harmonized standards applications.

Coalition for Digital Environmental Sustainability (CODES): CODES aims to help catalyse, coordinate and bring more strategic coherence to efforts to share knowledge, maximize impact and avoid duplication. It is co-championed by UNEP, UNDP, the International Science Council, the German Environment Agency, the Kenyan Ministry of Environment and Forestry, Future Earth and Sustainability in the Digital Age.

Atrium of blockchain: This platform supports learning, collaboration and conversation among the UN community and is part of the coalition of UN agencies including UNDP, UNICEF and the World Food Programme.

Climate Chain Coalition (CCC): A public-private consortium initiative initiated by the Secretariat of the UN Framework Convention on Climate Change that supports collaboration among members and stakeholders to advance blockchain to help mobilize climate finance and enhance MRV to scale climate actions for mitigation and adaptation.

International Association of Trusted Blockchain Applications (INATBA): Initiated by a project of the European Commission, INATBA's working group on climate action and energy facilitates collaboration on and harmonization of blockchain solutions for their issue domains.

Policies and regulations

The scalability of blockchain solutions relies not only on technological development, but also on government support through enabling policies. Scalability means the actual or potential capacity of the blockchain system to accommodate an increasing amount of work (World Bank 2018b). Considering policies and regulations is important in order to maximize the full potential of technologies. Based on a pilot project, Power Ledger suggests that the electricity tariff structure would need to be changed to attract energy consumers to join the energy trading that will be enabled through blockchain platforms (Green, Newman and Forse 2020).

While policies and regulations should not be counterproductive to innovative solutions for sustainable development, preventing any risks brought through them is also essential. To that end, in Malaysia, as industry is seeking clarity on blockchain regulations, the government is looking into what are the policy frameworks required to realize blockchain's potential, with adequate consideration of risks concerning the use of the technology. The Malaysian Industry-Government Group for High Technology (MIGHT) has been convening various industry stakeholders and ministries/agencies to identify potential opportunities to apply blockchain technology, as well as its regulatory implications[34]. Dialogue among industry, academia and policymakers through consultation meetings and workshops facilitates a better mutual understanding of how blockchain technology can be applied in the relevant issues.

Moreover, regulatory sandboxes, in which solutions building on blockchain and other innovative technologies could be tested in a controlled environment, can be beneficial to examine and explore the feasibility and challenges to applying blockchain to the relevant domains. The sandboxes can be a good approach to learn policy and regulatory implications from actual use cases. Several regulators in countries within the Organisation for Economic Co-operation and Development, as well as regulators in Australia, Bahrain, Canada, Hong Kong (China), Malaysia, Singapore, Switzerland, Thailand and the United Kingdom, have announced or implemented such sandboxes (Cognizant 2017; World Bank 2017; Schletz, Nassiry and Lee 2020). For instance, Malaysia's Sustainable Energy Development Authority (SEDA) started implementing a peer-to-peer energy trading under the regulatory sandbox in coordination with the Energy Commission.

All in all, it has not yet been the time to impose rigid regulations on the use of blockchain for energy and climate issues, considering the evolving nature of the technology's application (UN 2020c). At the same time, regulations should not inhibit innovations, although having agreeable soft rules and common standards might be necessary to foster the incorporation of technological innovation in energy and climate issues. The sandbox approach can help in this process.

34 Based on an interview with Ts. En. Hazril Izan Bahari from the Sustainable Energy Development Authority (SEDA) on 19 September 2020. See also MIGHT (2018).

4. Conclusion

As illustrated throughout this report, blockchain technology opens new pathways towards energy targets contained in the United Nations Sustainable Development Goals and the Paris Agreement. The possibilities are multiplied when blockchain is combined with standard and other new digital technologies such as sensor networks, Internet of Things devices, edge computing, smart meters, enhanced broadband networks, biometrics and artificial intelligence. Well-integrated digital solutions can generate significant impacts on sustainable energy access and mitigation of the ongoing climate crisis that were not even conceivable in past decades.

The emergence of new technologies within societies and industries requires the adjustment or creation of new policies and regulations. These can either boost or stall innovation. In the case of blockchain applications to electricity supply systems, for example, the trading of energy, carbon offset credits and any other values through blockchains would require the development of regulations on peer-to-peer payment. For instance, as described in section 2.1, it is important to modify current policies to enable peer-to-peer energy trading. Similarly, as illustrated in section 2.3, excess energy trading would negatively impact the economics of solar power projects in South Africa due to the underdevelopment of net-metering regulations.

Because digital technologies tend to develop faster than regulations, policymakers may want to consider positive and negative impacts brought from new technologies, and then adjust them in line with what expert peer-reviewed studies suggest for future energy systems. As another example, as Synergy Blockchain suggested in the context of the voluntary carbon offset crediting mechanism in China (see section 2.4), policy frameworks and guidelines play a key role in the design of climate actions that can be facilitated through blockchain platforms, but the development of such frameworks and guidelines might still be lacking.

Fostering an open and sincere dialogue between policymakers and industry stakeholders is vital to evaluate opportunities and risks on the use of blockchain, and especially to inform effective policies and regulatory bodies. Innovation business hubs have been engaging with governments on blockchain use cases to assess policy implications. Policymakers could benefit from such exchanges by gaining awareness of local use cases and how they can be adapted to local legal protocols, which might vary according to the country. Cross-country exchanges would eventually steer the harmonization of policy frameworks to some extent. Through participatory processes, policymakers would consider whether to adapt existing laws or to create new ones that facilitate the use of decentralized models. Blockchain and other new technologies can help in leapfrogging economies and legacy technologies in developing countries, but this is only possible in conducive regulatory environments that encourage investment (Mittal 2019).

Inter-operability issues are directly related to the scalability of blockchain solutions (UN 2021b): between blockchain solutions and legacy systems; and inter-operability between blockchain solutions. The first aspect, as elaborated in section 2.2, was addressed by the Energy Web Foundation, which demonstrated that the challenge of acquiring heterogeneous renewable energy generation data could be addressed via new APIs that integrate different sources of data into a blockchain-based platform. With regard to the second aspect, section 2.5 details ongoing efforts to apply blockchain to the measurement, reporting and verification (MRV) of greenhouse gas emission reductions. The Open Innovation Lab of Yale University explores (see section 3.1) the nested accounting process to enable inter-operability between blockchain solutions and to develop a seamless MRV system across multi-levels and multi-actors. This responds to a current challenge: the variety of MRV systems at different levels and policy frameworks, mostly working on separate streams, generating centralized data silos and preventing the exchange of data (GIZ 2019).

Finally, significant challenges remain to successfully deploy innovative solutions in an inclusive and equitable way, especially in the Global South. Digital infrastructures in low- and middle-income countries are frequently not sufficiently developed and maintained, and they present evident obstacles for technological development and its thorough use. Furthermore, blockchain and other new technologies must always be designed following human-centred approaches. Challenges within communities should guide the development of solutions, and community members should be part of the design, use and evaluation of digital solutions. Even if new technologies can offer alternatives, solutions will only be effective if they can be operated on the ground, employing or developing local capacities.

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