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USING BLOCKCHAIN TO SUPPORT THE ENERGY TRANSITION AND CLIMATE MARKETS

RESULTS AND LESSONS FROM A PILOT PROJECT IN CHILE

December 2020

WORLD BANK GROUP

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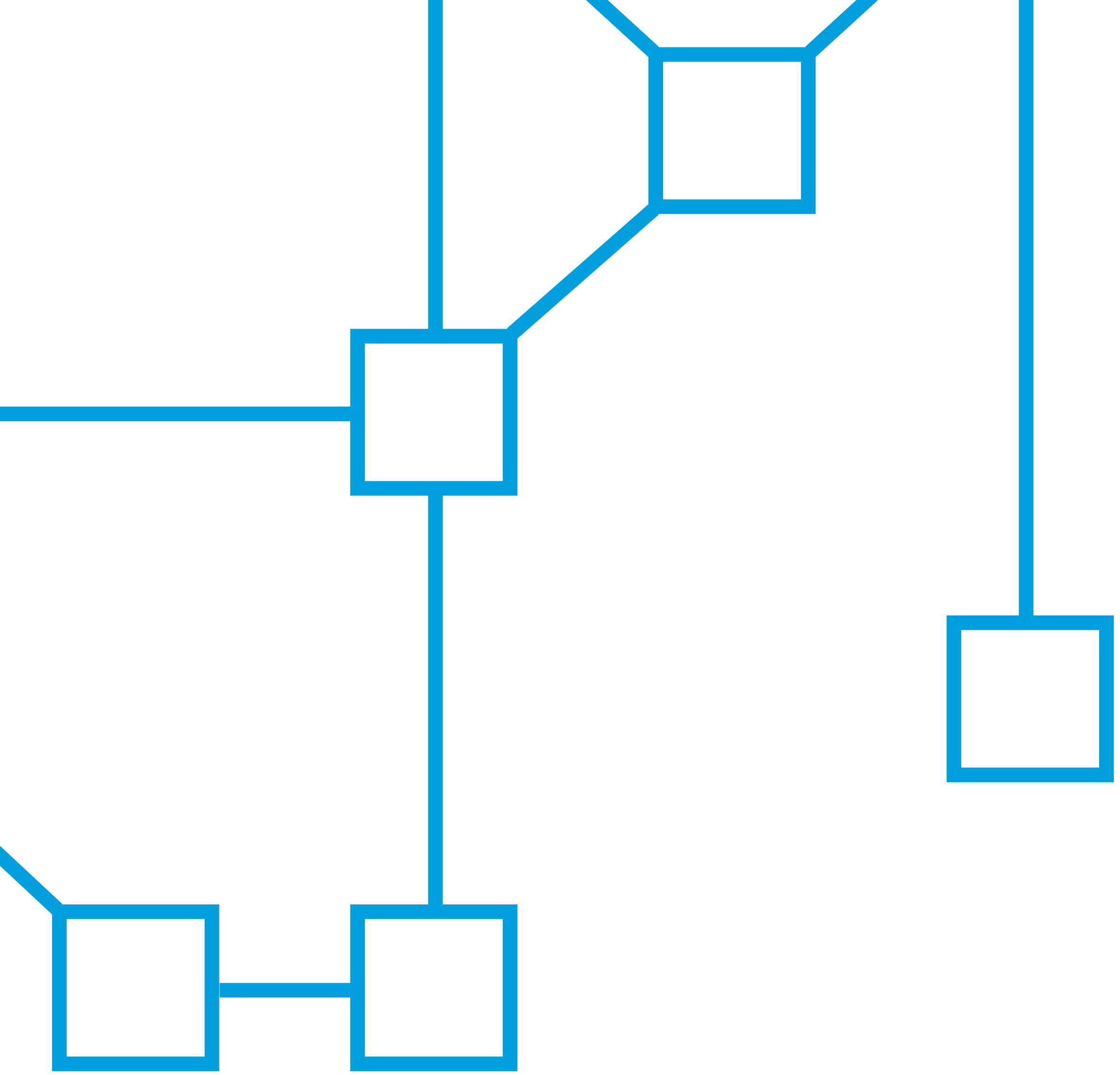
ABSTRACT

Countries can achieve a successful energy transition and participate effectively in the climate market by applying available knowledge, good practices, and lessons learned. This paper provides an example of how blockchain technology contribute to these goals by linking energy and climate sectors, businesses, and customers. It assesses a pilot blockchain project undertaken in Chile to support distributed generation and carbon markets. Recommendations for scaling up innovative technologies to advance clean energy and climate change mitigation agendas are adduced.



ACKNOWLEDGMENTS

This report was prepared by a core team comprised of Patricia Marcos, Florencia Sanchez Zunino, Susan Elaine David Carevic, Rachel Chi Kiu Mok and Rodrigo Pizarro.

The authors would like to express their sincere thanks and gratitude to Juan Pedro Searle (Ministry Energy Chile), Francisco Dall'Orso León (Ministry Energy Chile) and colleagues at Phineal for the support and guidance offered in the elaboration of this study, the timely feedback and the excellent collaboration throughout.

The team would also like to thank World Bank colleagues including Marianne Fay , Virginia Brandon, Bjorn Philipp, Chandra Shekhar, Stephanie Gil, Gabriela Elizondo, Stela Mocan, Stephanie Rogers, Janina Franco and Francisco Winter for the advice and guidance provided throughout the elaboration of this report.

The team would finally like to thank Nannel Gacitúa, who designed the cover and the layout and typeset the report.

CONTENTS

ABBREVIATIONS

CO_2	carbon dioxide
DER	distributed energy resources
ETS	emission trading scheme
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ITMO	internationally transferred mitigation outcome
MRV	monitoring, reporting, and verification
NDC	Nationally Determined Contribution
PTSP	Public Solar Roofs Program
PV	photovoltaic

EXECUTIVE SUMMARY

THE ROLE OF EMERGING TECHNOLOGIES IN THE TRANSITION TOWARD LOW-CARBON ENERGY

Energy markets all over the world are undergoing a transformation as new energy and information technologies are emerging and disrupting traditional market architectures. The emergence of blockchain-based utility suppliers, intelligent technology in energy storage, prosumers, and electric vehicles are creating new opportunities for energy generation, distribution, and demand. At the same time, climate change and rapid urbanization are posing critical energy challenges of multidimensional complexity.

The energy transition will play an essential role in reducing the risks and impacts of climate change. To meet the Paris Agreement objective of "pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels," annual energy-related carbon dioxide (CO2) emissions need to fall by more than 70 percent by 2050 (IRENA 2019b). The transition toward a low-carbon energy system will require the adoption of clean technologies, the digitalization of the sector, an enabling policy environment, and the identification of synergies within sectors. Experiences by countries that have started this transition can inform other countries.

Climate markets and carbon pricing can contribute to a low-carbon energy transition, because they offer the opportunity to scale up the resources mobilized from the private sector, reduce the burden of meeting commitments under the Nationally Determined Contributions (NDCs), and increase global ambition to mitigate climate change. Article 6 of the Paris Agreement recognizes that countries may engage in cooperative approaches, including the use of bilateral agreements, to ensure mitigation outcomes that contribute to individual NDCs.[1]

Emerging technologies can help achieve a low-carbon energy transition while catalyzing the development of climate markets. Technologies such as blockchain are rapidly shaping the society of the future.

Blockchain is emerging as a disruptor of the energy sector, because it can manage complex contracts and facilitate trade among multiple entities and producers. It could be instrumental in managing the growing complexity of the energy sector as well as data security and resource ownership. The sector has been slow to recognize blockchain's potential, however, and awareness across the industry is lacking.

One of the uses that is gaining most traction is the trading of distributed energy resources (DER). Owners of small-scale generation sell excess generation directly to other consumers. The flow of electricity is coded into the blockchain, and algorithms match buyers and sellers in real time based on preferences. Smart contracts then execute automatically when electricity is delivered, triggering payment from buyer to seller. Removing financial transactions and the execution of contractual commitments from central control brings a new level of decentralization and transparency.

Blockchain has the potential to play a significant role in the next generation of climate markets in the post–Paris Agreement era. All markets trading assets associated with emissions reductions, whatever their structure or governance, require centralized registries. The result is a multitude of trading instruments operating within closed technological systems following differing rules. Emerging digital innovations (principally blockchain), through the definition and design of new governance structures and operating models, could enable a new architecture for climate markets based on decentralization, transparency, and cost-effectiveness.

Governments and businesses around the world are taking steps to spur the adoption of emerging technologies at scale. The question is no longer whether emerging technologies work but how they can be integrated into businesses and policies.

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[1] Article 6 (which has not yet been finalized) recognizes that countries may use internationally transferred mitigation outcomes (ITMOs) toward their individual NDCs. ITMOs are mechanisms through which countries negotiate bilaterally for climate actions that have mitigation outcomes and can be transferred between cooperative parties. In effect, Article 6 recognizes the exchange of reductions in carbon emissions across jurisdictions.

CHILE'S PUBLIC SOLAR ROOFTOP PROGRAM

The government of Chile, with support from the World Bank and the Partnership for Market Readiness (PMR), kickstarted the entry of disruptive technologies into the energy sector by pioneering the use of blockchain in the electricity sector.[2] Its efforts build on the country's Public Solar Rooftop Program for self-consumption in public buildings and create mitigation outcomes to be recorded in the national registry of Chile's energy sector and reflected in the World Bank's Climate Warehouse for Mitigation Outcomes. This warehouse will provide visibility on mitigation outcome transactions and will enable buyers and sellers to find and compare projects and the associated mitigation outcomes, demonstrating a decentralized information technology approach to connect climate market systems.[3]

The Public Solar Rooftop Pilot has pushed innovation within the Chilean Ministry of Energy. It comes at a very relevant time, as it helps Chile achieve its strategy for a low-emission and resilient energy sector, contribute to the country's NDC goals, and decarbonize the transition to a greener economy. The Ministry of Energy is committed to the transition toward a low-carbon economy and has played a leading role in Chile's climate change agenda.

THE PURPOSE OF THIS PAPER

It provides a timely input for the continued negotiations on international cooperation on carbon markets (Article 6) and the possibility of developing climate markets across national jurisdictions and trade associations. Although the Paris Agreement work program was agreed to at the United Nations Conference of the Parties (COP) 24, in 2018 in Katowice, clarity is still lacking in many areas regarding how to operationalize the next generation of climate markets under Article 6. Pilot activities like Chile's public solar rooftop blockchain project could play a key role in testing new operating models and accelerating the development of emerging technologies.

The rest of this paper is organized as follows:

- What Is Blockchain Technology?
- The Energy Transition
- Chile's Energy and Climate Policy
- Chile's Public Solar Rooftop Pilot Project
- Results and Lessons Learned
- Conclusions

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[2] For information on the Partnership for Market Readiness, see https://www.thepmr.org/.
[3] For information on the Climate Warehouse for Mitigation Outcomes, see https://www.worldbank.org/en/programs/climate-warehouse.

1. WHAT IS BLOCKCHAIN TECHNOLOGY?

> A blockchain is a shared ledger of transactions between parties in a network, not controlled by a single central authority. One can think of a ledger like a record book: it records and stores all transactions between users in chronological order. Instead of one authority controlling this ledger (like a bank), an identical copy of the ledger is held by all users on the network, called nodes.
>
> –OECD Blockchain Primer (https://www.oecd.org/finance/OECD-Blockchain-Primer.pdf)

Through a decentralized structure, blockchain technology records information of interest to a given network of participants by sequentially capturing and registering blocks of data. In this way, it constructs a decentralized record-keeping system shared by all members of the network. It is particularly useful for registry functions involving multiple entities or data feeds that require secure and transparent transactions.

Blockchain operates by using programming algorithms to time-stamp blocks of encrypted, mostly transactional data, and link them sequentially. New blocks are added to the blockchain at timed intervals and "chained" together by inserting into the new block a "hash," or digital fingerprint of the data in the previous block. The new block is then broadcast to all of the other computers, or "nodes," that encompass the blockchain network, making the ledger nearly immutable–that is, almost impossible to alter. As the ledger and the number of computers or nodes that support the ledger grow, the security and immutability of the blockchain network increases.

Blockchain technology is best known for its use as the underpinning architecture for cryptocurrencies, such as bitcoin, to facilitate financial transactions.[4] But there are other important functions and reasons for the use of blockchain (including more secure storage/tracking of data such as energy generation, CO2 emissions, land registry information, supply chain transactions). Blockchain delivers best in synergy with other emerging technologies (such as advanced energy metering infrastructure). The business value of interconnects between new technologies to potentially combine with each other is underlined by their capability to address unmet market needs, create new products/services/solutions due to the uniqueness of their combined potential, and drive unlikely players from diverse industries to work with each other. The World Economic Forum has identified blockchain technology as one of the six megatrends underpinning the transition toward a digital and connected world (WEF 2015).

Chile's Public Solar Rooftop Pilot Project, described in this paper, is a blockchain network in which computer servers or nodes capture data from an electricity meter, then store and hash this information in predetermined time blocks to a blockchain created for the project.

Blockchain algorithms can also program transactions or trades across participants with an if-then code. These predetermined commands can be digitally encrypted in a smart meter application or a "smart contract," thereby facilitating trade between consumers or producers. Potential transactions requiring the approval of both parties can be built into the application, with all information pertaining to the transactions recorded securely in the blockchain structure. All nodes within the network will have the same transaction parameters and host the results of the transaction. In this way, blockchains ensure that the same transaction cannot occur twice. These processes can be automated through blockchain applications. Blockchain not only registers data in a secure and transparent way; it also, through applications that use smart contracts, can coordinate multiple trades across many participants in a network, in effect solving the problem of market coordination. For example, a prosumer (an end user who both consumes and produces electricity) can program the sale of excess electricity at a predetermined price, and a consumer can accept energy at this price under certain conditions. If both agree to the trade, the exchange occurs. It is then automatically registered in the shared ledger. This system eliminates the need for a trusted intermediary or centralized registry.

Figure 1 presents the blockchain process schematically, beginning with data block number 6. As electricity is generated, data on emissions and solar radiation are recorded through sensors and captured by the network nodes every 15 minutes and put into a new block. The data collected are hashed and saved to the block, along with the hash of the previous block. In the figure, for example, Data Block 7 has been issued hash number 7657grt64; the block also contains the hash number of the previous Data Block 6 (3457hfg64).

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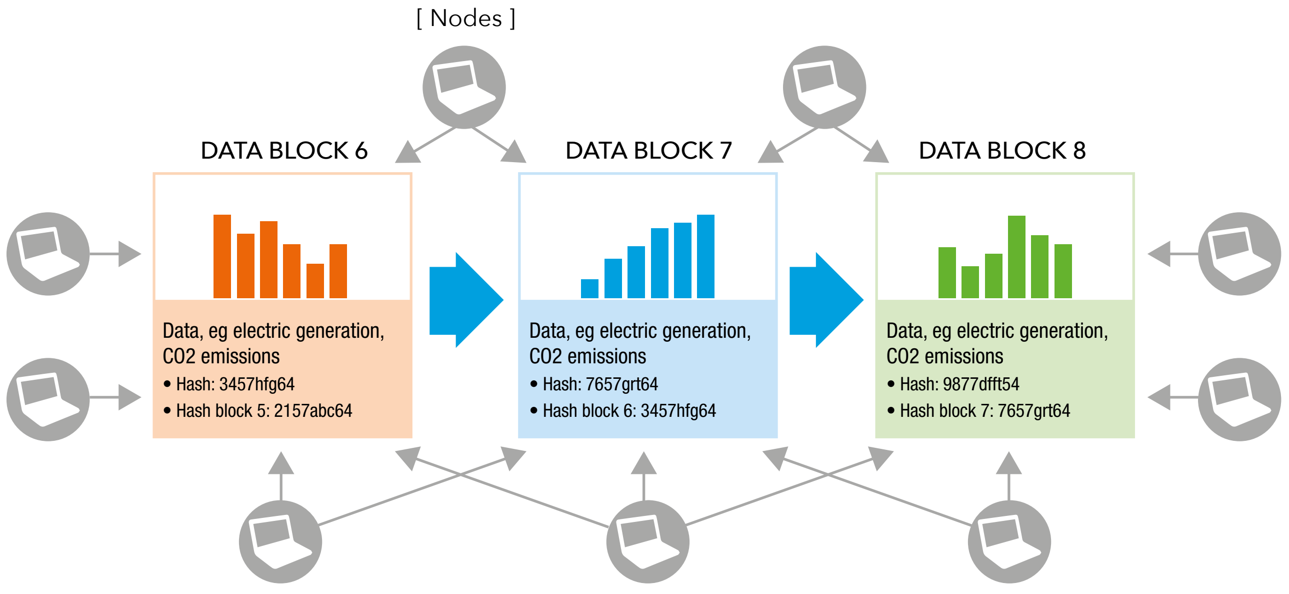
[4] Cryptocurrencies are digital means of payment and stores of wealth. The best known is bitcoin.

Figure 1

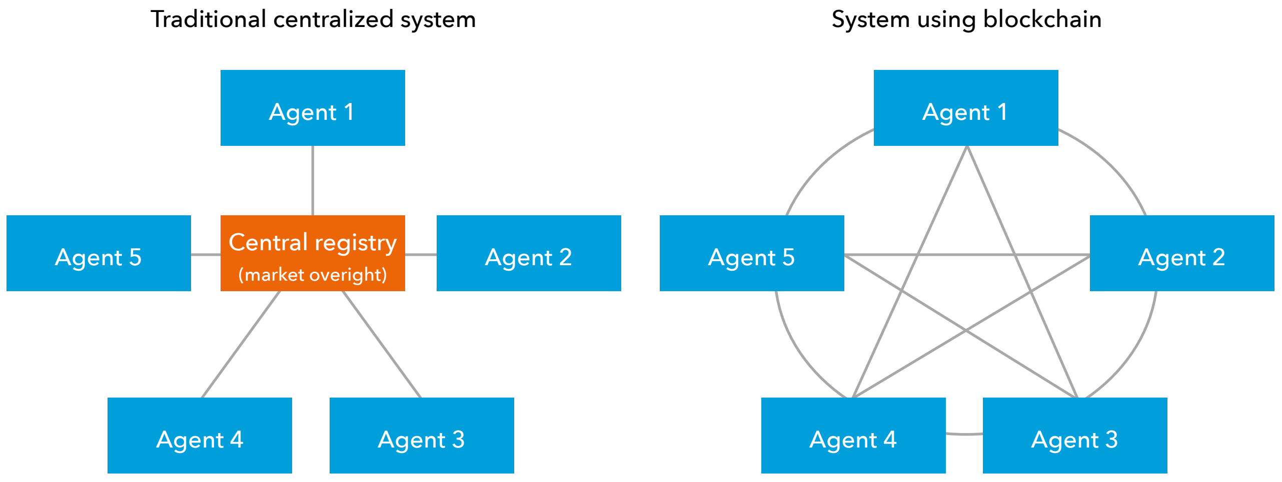
How blockchain works



Because it can execute transactions without the need for trusted intermediaries and a centralized registry system, blockchain is usually referred to as a peer-to-peer network (figure 2). Blockchain has the potential to significantly reduce the transaction costs associated with trades or regulated contracts.

Figure 2

Traditional centralized registry system and system using blockchain



The main advantage of blockchain is that it solves the coordination problem across multiple market participants—without a centralized intermediary that records transactions. Thus, it can facilitate transparency, reduce the costs of each transaction, and reduce information asymmetries in the markets in which it is applied. These benefits are especially relevant for complex transactions with multiple traders that require a tamper-proof system that supports energy trading and carbon markets.

A blockchain system has a number of variable features—chief among them the openness of the platform (public or private) and the level of permissions required to add information to the blockchain. A "public blockchain" is an open network in which anyone can read, write (i.e., generate transactions for the ledger to record), or participate (i.e., verify new blocks for addition to the chain); whereas a "private blockchain" is an invitation-only network governed by a single entity. Private blockchains allow organizations to employ distributed ledger technology without making data public. Similarly, a "permissioned blockchain" needs prior approval before use, whereas a "permissionless blockchain" lets anyone host a node and add data to the ledger.

Each structure has advantages and disadvantages. The decision about which blockchain structure to adopt will depend on the specific objectives of the system to be built, the nature of transactions, and the type of market (Peter 2019) as well as cost considerations.

In summary, blockchains deliver capabilities that are very attractive to most of the sectors/industries, i.e. data reliability, accurate chain of custody tracking, improved traceability, and product visibility. However, as is the case with any information system, blockchain faces a complex and potentially controversial array of issues that need to be properly addressed during the design of the blockchain information system. Among the most important issues are: (i) quality of its data, (ii) regulation and governance; and (iii) potential difficulties with interoperability between blockchains and with existing systems.

2. THE ENERGY TRANSITION

In the last two centuries, the world experienced at least two major energy transitions—from biomass to coal, and then from coal to liquid fossil fuels (Kander, Malanima, and Warde 2013). There is now evidence that a new energy transition—toward renewable sources, changes in the structure of the energy market, and the emergence of distributed energy resources (DERs) and prosumers—is underway.

FEATURES OF THE ENERGY TRANSITION

The growing share of renewables

According to the International Energy Agency (IEA), the share of renewables in meeting global energy demand is expected to reach 12.4 percent in 2023, a 20% expansion from 2018. Renewables will enjoy the fastest growth in the electricity sector, providing almost 30 percent of power demand in 2023, up from 24 percent in 2017. During this period, renewables are projected to meet more than 70 percent of the global growth in electricity generation, led by solar photovoltaic (PV) and followed by wind, hydropower, and bioenergy. Hydropower remains the largest renewable source, meeting 16 percent of global electricity demand by 2023, followed by wind (6 percent), solar PV (4 percent), and bioenergy (3 percent) (IEA 2019).

The accelerated pace of renewable energy sources in the energy mix is the consequence of both concern over climate change and the increased rate of technological innovation in the industry. According to the International Renewable Energy Agency (IRENA), the installed costs of utility-scale solar PV projects fell by 74 percent between 2010 and 2017, from $4,621 per kilowatt (Kw) to $1,210. Installation costs for newly commissioned onshore wind projects fell by 22 percent in the same period (from $1,913 per Kw to $1,497 (IRENA 2019a).

The increase in storage capacity

Storage capacity has also increased. According to IRENA, electricity storage will triple by 2030, and costs could fall by more than half (IRENA 2017). Associated technologies, such as electric cars, may increase demand for renewable energy sources but also contribute to the development of new energy solutions and the co-management of energy generation and demand.

The advent of "prosumers" and distributed energy resources

The growth of solar panel technology and the increased capacity for storage have created new opportunities for consumers. The availability of smart devices in the home has triggered demand for the continuous monitoring and control of electricity consumption, as consumers are starting to explore ways to optimize and manage their consumption. This development is increasing efficiency, opening an avenue for consumers as producers of energy generation (prosumers).

Utilities' business models have changed as well. One important innovation is DERs—small or medium-size installations connected to the distribution network or near the end user that can potentially provide services to the electric power system (European Commission 2015). Principally, but not exclusively, DERs generate solar PV power. Distributed solar PV energy is considered one of the most attractive renewable energy resources because of its economy, safety, low infrastructure costs, and low marginal cost. The distributed generation market is expected to exceed $573 billion by 2025 (Grandview Research 2018).

DER solutions will play a key role as global urbanization advances. About 55 percent of the world's population currently lives in urban areas. This figure is expected to rise to 68 percent by 2050 (UN DESA 2019). Urbanization will put enormous pressure on energy systems—but it can also facilitate innovative DER solutions.

THE ROLE OF NEW TECHNOLOGIES IN THE ENERGY TRANSITION

New energy technologies for storage, DER, information technologies, the utilities of the future, and electromobility are among the technologies driving the on-going energy transition. The digitalization of the energy sector, although slow, is especially relevant; it is already causing some large multinational energy companies to introduce major changes to their traditional modus operandi:

- Corporate structures now include digital and data science organizational arms. Corporations are hiring data scientists and cloud architects.
- Corporations are partnering with start-ups to learn more quickly and remain competitive—particularly on data analytics, machine learning, and cloud architecture.
- Corporations are acquiring companies that operate on the retail side, such as aggregation platforms, the Internet of Things (IoT), and machine learning platforms.
- Corporations are introducing digital academies and hubs to bring employees up to speed with ongoing disruptive trends.

In the traditional energy market, energy users buy electricity from power utilities. In a smart grid, energy users are both consumers and suppliers (prosumers) of energy, as surplus renewable energy generation can be traded with the utility and other users. The decentralized and secure nature of blockchain technology could bean enabler for smart grids and could accelerate the ongoing energy transition to decarbonized and smarter energy systems, addressing some of the challenges the industry is facing.

The energy industry (particularly electricity) is increasingly becoming customer-centric—and customers have shown mounting interest in self-generation and in selling power to the grid. Customers are also demanding energy management services and more transparent energy data from their energy providers, thus increasing their ability to make decisions about their own energy use and about the providers they choose to supply them with energy services. New technologies will power the energy management services demanded by tomorrow's energy customers.

This is the context in which blockchain technology must be understood.

THE POTENTIAL BENEFITS OF BLOCKCHAIN IN THE ELECTRICITY SECTOR

As blockchain is based on peer-to-peer (P2P) transactions, it can reduce the additional and significant regulatory costs of intermediary institutions that regulate contracts. In this way, it provides a feasible means for direct electricity transactions between microgrids. In addition, blockchain can provide a publicly available charging infrastructure for electric cars that tackles the challenge of limited range by enabling individuals to make their private charging stations available for public use for a fee.

Various companies have created blockchain applications in the sector (box 1).

Box 1

Examples of the use of blockchain in the energy sector

Enerchain.

In May 2017, the German software company Ponton launched the first platform to trade energy products over the counter using blockchain. Participants in the gas and electricity generation markets can validate and certify transactions without the involvement of a third party, reducing transaction costs, increasing the efficiency of the value chain, and ensuring safe and fast transactions. In the initial (pilot) version, 39 German power and gas generators participated. In May 2019, the platform was officially launched, allowing its use throughout Europe. Participating companies include Iberdrola (a Spanish energy company), Total (a French oil company), RWE (a German energy company), and Enel (an Italian energy company).

The Energy Origin.

TEO is a web platform based on blockchain that improves the traceability of the renewable energy consumed by revealing its origin in real time. Notably, the platform reveals to consumers whether they are using renewable energy. Using blockchain, the system allows producers to connect to the platform and displays the corresponding certificates of authenticity. The platform is currently used by Engie, a producer of renewable energy, and AirProducts, a manufacturer. TEO provides daily, tamper-proof certification and tracks the amount of renewable energy injected into the network (by Engie) and the amount of electricity consumed at the industrial site (by AirProducts).

Greenchain.

ACCIONA Energía, a Spanish renewable energy company, launched the Greenchain blockchain project to improve the traceability of renewable energy generated worldwide. It allows consumers to check, in real time, the origin of the renewable energy they are consuming. Five hydroelectric and wind generators in Spain and four corporate clients in Portugal are piloting the project, which will then be scaled up to countries such as Mexico and Chile.

Powerledger. A software that allows for peer-to-peer energy trading from rooftop solar panels. It uses blockchain technology to empower households to trade their excess rooftop solar power with their neighbours. The technology can also be used to trade renewable energy and environmental commodities.

Bitlumens.

BitLumens is building a decentralized, blockchain-based micro power-grid for the 1.2 billion people without access to electricity and banking. It uses blockchain for transactions and payments through a token. Villagers can buy tokens that are used for pay-as-you-go electricity and rent-to-own equipment. Tokens could also be used for remittance or crowdfunding purchases of electricity on behalf of recipients. The company earns money through sales of equipment.

Sun Exchange.

The business model pertains to funding panel equipment. It purchases solar cells and lease them to schools and businesses in emerging markets. People from around the world can buy panels and lease them to recipients and receive dividends for doing so.

BLOCKCHAIN AND CLIMATE MARKETS

Two conditions must be met for carbon markets to emerge. First, the international climate negotiation framework must recognize that mitigation outcomes can be transferred across jurisdictions. Internationally transferred mitigation outcomes (ITMOs) refer to any carbon-based trades affecting Nationally Determined Contributions (NDCs). ITMOs and market trades of carbon emissions are regulated under Article 6 of the Paris Agreement, the negotiation of which has not yet been finalized (box 2). According to one study, effective Article 6 trading rules could save up to $250 billion a year on climate action by 2030. [5]

Second, the significant transaction costs associated with carbon markets must be reduced. In carbon markets, transaction costs are incurred in connection with information asymmetries, coordination, oversight of emissions trading, and the accounting structure through which trades are registered.[6] All these institutional and governance structures, and therefore costs, could be significantly reduced if they are well-designed and agreed among all carbon market parties and complemented by blockchain technology in decentralized carbon markets.

In the absence of a structured market [7], governments must identify a national registry and accounting systems that are secure and can register emissions reductions and trades within a specific market. Maintaining such a registry is extremely costly and involves massive coordination and information security issues, especially across jurisdictions and legal systems. The difficulty of maintaining these registries is one of the principal problems hindering the emergence of integrated carbon markets across the world. [8]

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[5] See https://www.ieta.org/resources/International_WG/Article6/CLPC_A6%20report_no%20crops.pdf

[6] A few studies have been conducted on transaction costs in carbon markets, but they center on monitoring, reporting, and verification. Examples include Schleich and Betz (2004); Jaraite, Convery, and Di Maria (2010); Mundaca and others (2013); Joas and Flachsland (2014); and Kerr and Dusch (2015). Michaelowa and Stronzik (2002) review the transaction costs of implementing the Clean Development Mechanism, concluding that they may be considerable. Krey (2004) reaches the same conclusion for India.

[7] Article 6 of the Paris Agreement recognizes the heterogeneity of approaches, providing a basis for countries to voluntarily cooperate with each other to deliver on their NDCs and raise ambition. This Article signals the use of carbon markets globally, allowing for decentralized bilateral cooperation approaches, including through internationally transferred mitigation outcomes. Emerging technologies has enabled increased data availability, systems automation, smart grid applications and data transfer, grid management, technological systems, and diverse governance rules. Information about mitigation outcomes is collected in a variety of repositories, including spreadsheets, databases reflecting pipeline activities, and registries at the country, regional, or institutional level. The new generation of climate markets is likely to develop as a network of decentralized markets, linking at regional, national and subnational levels, without centralized functions and processes.

[8] It has been argued that one of the principal problems of the Clean Development Mechanism under the Kyoto Protocol were its transaction costs (see Chadwick 2006).

Box 2

The United Nations Framework Convention on Climate Change and the Paris Agreement

The centerpiece of the international climate governance regime is the UN Framework Convention on Climate Change (UNFCCC), adopted at the 1992 Rio Conference. The convention established a broad set of principles, including the principle of common but differentiated responsibilities.

On December 12, 2015, at the Conference of Parties (COP) 21 in Paris, parties to the UNFCCC reached a landmark agreement to combat climate change and accelerate and intensify the actions and investments needed to achieve a sustainable low-carbon future. Builds on the UFCCC, the Paris Agreement established a new framework for global cooperation by all parties to the convention.[a] In that way, it unites all countries in a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. It also provides for enhanced support to help developing countries to pursue those goals.

The basis of the Paris Agreement is a nonbinding bottom-up approach (in contrast to the top-down structure of the Kyoto Protocol). The agreement. It sets a goal of limiting average global warming to 2°C (and identifies the need to confine increases to 1.5°), which it seeks to achieve by requiring all parties to submit plans for their “nationally determined contributions” (NDCs)–country policy commitments that are unilaterally determined, voluntary, and nonbinding–and to make their NDCs increasingly ambitious over time.

The agreement specifies the need for international financial support for developing countries with respect to both mitigation and adaptation. The accompanying COP Decision, also nonbinding, reiterates the goal of contributions of $100 billion for this purpose. The agreement also sets out the need for support for capacity building, technology transfer, and climate education.

Market instruments and carbon pricing have been identified as relevant policy instruments for achieving the Paris Agreement targets. Article 6 of the Paris Agreement (which has not yet been negotiated is especially important, as it gives new life to carbon markets and cooperative mechanisms.

[a]. In 2019, under President Trump, the United States withdrew from the agreement.

3. CHILE'S ENERGY AND CLIMATE POLICY

CLIMATE POLICY

Chile has positioned itself as a global leader in international climate policy. It has committed to phase out coal by 2040 and move toward carbon neutrality by 2050. Because the energy sector is the main contributor to greenhouse gas emissions, accounting for 78 percent of total national emissions (MMA 2018), and electricity generation is the principal contributor in the energy sector, accounting for 53 percent of emissions (MMA 2018), efforts have focused on promoting renewable energy sources, pursuing distributed energy alternatives, incentivizing energy efficiency, and regulating emissions reductions.

Under the Paris Agreement, Chile committed to reduce the CO2 intensity of its GDP by 30 percent by 2030 from its 2007 level. That translates to a reduction from 1.02 tCO2e/C$ (Chilean pesos) million in 2007 to 0.71 tCO2e/C$ million in 2030.[9] In addition, and subject to international funds, it has a conditional commitment to reduce the CO2 intensity of GDP to 35–45 percent of the 2007 level. Chile has been among the first countries to update its NDC. The updated NDC has a more ambitious mitigation goal, with an absolute goal at 95 Mton by 2030, earlier peak of emissions in 2025, and lower carbon budget of 1110 Mton for the 11-year period[10] , showing therefore its commitment to the international climate agenda.

In April 2018, the Ministry of Energy launched the Energy Roadmap 2018–2022, which includes climate change as a cross-cutting issue in the roadmap's seven priority areas. In January 2020, the government sent to Congress the first national climate change law, legally binding Chile's commitment to achieve carbon neutrality by 2050 and to phase out coal-fired generation by 2040. Chile's present energy grid includes 28 coal-fired power plants, with an average age of 18 years, which emit 26 percent of all greenhouse gases while contributing just 4 percent of the country's power generation. Chile's low-emission energy strategy will make the country a pioneer in the fulfilment of international targets to reduce emissions.

To further advance the energy transition, the government has set a new, more ambitious target of generating 20 percent of the country's energy and 45 percent of all electric generation from renewable sources by 2025. To comply with its decarbonization commitment, Chile will phase out eight coal plants through a voluntary agreement with power generation companies. These plants represent 19 percent of the total installed capacity of coal-fired power plants, with a capacity of 1,047 megawatt tons (MWt). the expectation is to cover the shortfall with renewable energy generation. There is no schedule yet for phasing out the remaining 20 plants.

Chile has enormous potential in renewable energies, particularly solar and wind energy generation. Some estimations suggest that by 2030 up to 75 percent of electric power generation in Chile could come from renewable sources (PSR and Moray Energy 2018). The energy transition—and the use of market instruments—may be the key to accelerating Chile's emissions reduction targets.

Chile is also exploring the development of a strategy for participating in integrated carbon markets.[11] It is a member of the Pacific Alliance (a trading association made up of Chile, Colombia, Mexico, and Peru), which has committed to move toward sustainable economic growth, and created a Green Growth Group to discuss mechanisms to advance collaboration in the development of carbon markets. It also belongs to the Carbon Pricing Leadership Coalition, a World Bank-led coalition of countries and corporations committed to carbon pricing, and supports the Carbon Pricing of Americas initiative, an initiative of national and subnational jurisdictions in the Americas aimed at promoting dialogue on carbon pricing and integrated carbon markets.

Chile implemented a carbon tax in 2017.[12] The tax is significant because it is the only one in the region explicitly based on emissions, not carbon fuel content. It is therefore the most likely tax in the region to support progress toward more sophisticated market instruments.

A tax reform bill currently before Congress proposes a carbon emission offset scheme to compensate for the tax. If passed, it would be the first offset scheme in the region with these characteristics.

In recent years, various jurisdictions in the Western Hemisphere have implemented carbon pricing to support efforts to mitigate climate change. Argentina, Colombia, and Mexico, like Chile, have imposed carbon taxes. In North America, California and Quebec have an integrated Emissions Trading System through the Western Climate Initiative, and U.S. states in the northeast have an integrated emissions trading scheme for electricity generation companies known as RGGI (see https://www.carbonpricingleadership.org/).

Several continental initiatives seek to promote further links across Latin American jurisdictions and between North and South American jurisdictions. Among them are efforts through the Pacific Alliance and a recent initiative promoting a carbon market of the Americas.

Major bottlenecks remain, such as integrating criteria, methodologies, institutions and objectives, and dealing with the transaction costs of markets for carbon emissions.

It is not clear how to fully operationalize a market-based offset mechanism in a country like Chile, with its limited financial and human resources and small number of taxable facilities, or more broadly across the region. A new registry system and monitoring, reporting, and verification protocols will almost certainly be necessary.[13] Of concern is how to achieve the necessary level of information security for operation of a tax with offsets or a broader carbon market. According to one study, Chile lacks the capacity to achieve a minimum level of cybersecurity; a carbon market or offsetting scheme would require millions of dollars of investment.[14] The transactions cost problem, and the required level of security, could be solved by adopting blockchain technology, as shown in chapter 4.

ENERGY POLICY

Chile's energy policy was built through a broad participatory process (ChileEnergía 2050). It establishes guidelines and goals for the development of a reliable, sustainable, inclusive, and competitive energy sector (box 3). The policy is based on four pillars, each of which has specific goals and targets for 2035 and 2050.[15]

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[9] In addition, Chile has committed to the sustainable development and recovery of 100,000 hectares of forested land area.

[10] https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Chile%20First/Chile’s_NDC_2020_english.pdf

[11] Integration of carbon markets has proved to be challenging due to their bottom-up nature. Climate markets worldwide have different scope and approaches, which add to the complexity of market integration and trading across borders. Using the warehouse example, blockchain has the potential to facilitate communication between bottom-up markets, track assets across different systems and avoid double counting.

[12] The government of President Bachelet (2014–18) implemented a $5 per ton tax on CO2 emissions in 2017 (General Tax Reform Bill, Law Nº 20.780) on facilities in various sectors, including food-processing, refining, and electricity. In 2017, 96 facilities were taxed, raising $191 million in revenue. The CO2 tax covered about 40 percent of the country's carbon emissions.

[13] The Ministry of Energy, with support from the World Bank, is now developing such a system.

[14] Achieving an acceptable level of security at the Ministry of the Environment and the Superintendency of the Environment, the agencies that regulate and operate the current tax, would require an investment of almost $17 million (over a three-year horizon) for the tax currently being implemented (Deloitte 2017). Moving toward an Emission Trading Scheme (ETS) or an offset mechanism would require even more resources for design and implementation, as well as a significant investment in information security to reach the level of security of banks.

[15] The relevant goals for 2035 include the following: (a) "a fully bidirectional energy system with information technologies allowing both the production and management of energy at all levels"; (b) "at least 60 percent of renewable energy in the national electricity generation"; and (c) for 2050, "greenhouse gas emissions from the Chilean energy sector [that] are consistent with the limits defined by science at the level global and with the corresponding national reduction goal, promoting cost-effective mitigation measures."

Box 3

Key policy innovations promoting renewable energy in Chile

The Renewable Energy Law (Law 20257).

The first important reform for the renewable energy sector was the approval of a Renewable Energy Law, which included a renewable portfolio standard. An RPS is a quota system that encourages renewable energy generation by setting the proportion of electricity supply that must be produced from eligible renewable energy sources. Renewable energy technologies were first added to the energy mix in Chile in 2008, with the approval of Law 20257, which aimed to support the generation of electricity from nonconventional renewable sources, such as biomass, small hydraulic energy (capacity of less than 20 MW), geothermal energy, solar energy, wind power, and marine energy. This law was amended in 2013 (Law 20698, better known as Law 20/25), which states that renewable energy must make up 20 percent of the energy mix in Chile by 2025.

Restructuring public auctions.

Chile improved the ability of generators of renewable energy to compete in energy auctions. Renewable energy projects without a power purchase agreement used to face significant obstacles obtaining funding from commercial banks. PPAs can be achieved in Chile through bilateral negotiations or participation in power auctions—carried out by the National Energy Commission (CNE)—for regulated consumers served by the distribution grid.

Since 2005, Law 20018 has required electricity distribution companies to contract their energy requirements by means of competitive nondiscriminatory auctions (including renewables). A submitted bid with the lowest price is awarded a long-term contract (typically, a PPA for the project). In 2014 three-time blocks were established in the bidding process, covering 11 pm–8 am, 8 am–6 pm, and 6–11 pm (peak demand). This modification in the structure of the auction scheme greatly favored renewable generators, which can offer power cheaply at the times of the day they produce it.

In the latest and largest energy auction ever, the CNE had the goal of adding generation of 12,430 GWh/year, consisting of five-time blocks for 20 years starting in 2021. This auction covered 30 percent of Chile's energy demand (Ministry of Energy 2016). Wind and solar PV projects were awarded about 40 percent of the energy at the auctions. The efficient and competitive nature of auctions has reduced energy costs, encouraging further investment in the sector.

Energy transmission.

Law 20936 on electricity transmission, adopted in July 2016 aims to create a robust interconnected transmission system that allows the unification of Chile's power grid by connecting the Northern Interconnected System with the Central Interconnected System. The interconnection of the systems will allow two medium-size markets to merge, forming a more competitive marketplace and allowing the energy generated from large solar potentials in the north to be distributed to the central and southern part of the country.

Distributed energy.

The key regulatory instruments for distributed energy are Law 19940 and Law 20571, adopted in March 2004 and March 2012, respectively. Law 19940 grants distribution projects below 9 MW the right to connect to the grid, creating a market for small energy generators (i.e., those with installed capacity of up to 9MW).[a]

Law 20571 authorizes a system of net billing of residential generators.[b] It regulates self-generation of energy based on nonconventional renewable energies and efficient cogeneration. The law gives users the right to sell their surplus directly to the electricity distributor at a regulated price through net billing.

[a] Small energy generators are regulated by D.S. N° 244 of the Ministry of Economy and D.S. N° 101 of the Ministry of Energy.

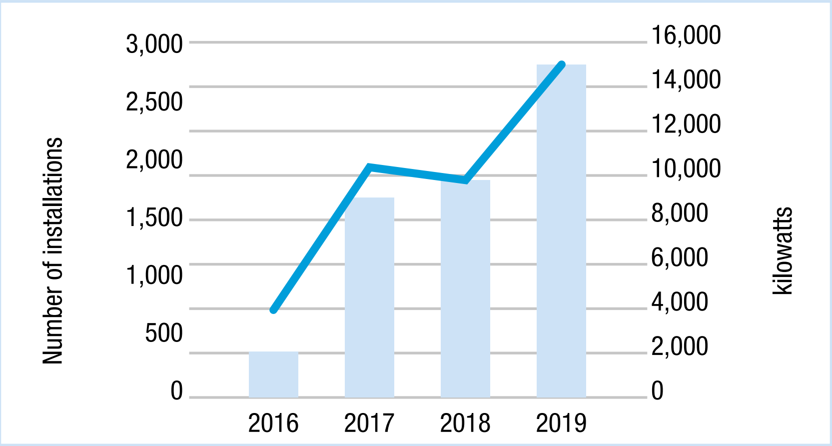
[b] Net billing pays the retail rate for customer-consumed generation and a below retail rate for exported generation.

Thanks to Chile's generous endowment of renewable energy sources, the significant decline in installed capacity prices, and a series of innovative policy instruments (see box 3), the country has experienced a remarkable energy transformation in the last few years. Installed capacity in nonconventional renewable energy sources (excluding large hydroelectric) increased sharply, from practically zero in 2008 to 21 percent of all energy sold in 2018 (CNE 2018).[16] Total generation was 76.2 GWh in 2018, of which 34 GWh were renewable and 10.8 GWh were nonconventional renewable, principally wind and solar (CNE 2018). Chile's policies have been so successful that the government's commitment of decarbonization by 2040 and carbon neutrality by 2050 will be met by renewable energy.

Chile has great potential in solar renewable energy but distributed solar PV generation has yet to take off (figure 3). One reason why is the high initial upfront investment (for solar panels, for example) of DER installations. The payback period is estimated at 8–14 years, depending on the system installed (CNE 2019). To incentivize investment with such a long payback period, the government has implemented a series of subsidies to support the distributed energy market.

Figure 3

Number and kilowatts of distributed energy installations in Chile, 2016–19



Source: Ministry of Energy of Chile.

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[16] These figures exclude large hydroelectric generation, which has about 23,315 MW of installed capacity (CNE 2018).

4. CHILE'S PUBLIC SOLAR ROOFTOP PROJECT AND ITS BLOCKCHAIN PILOT

In 2014, Chile's Ministry of Energy created the Public Solar Roofs Program (known as PTSP, its Spanish acronym) to support the installation of PV systems in public buildings.[17] The objectives of the $13 million program were to reduce the cost of operating public buildings, stimulate the market for PV solutions through the installation of solar panels, and generate free public access to information on the costs and conditions of PV projects aimed at self-consumption.

The project explored the potential of a blockchain-based monitoring, reporting, and verification system that validates and registers electricity generation certificates and, concomitantly, emissions reductions. That exploration led to the implementation of a pilot blockchain project, the ultimate goal of which was the creation of an institutional infrastructure to foster the growth of a carbon market capable of generating the funds required for initial investments in DER installations. It is worth clarifying that at the date of this report, Chile does not have an emission trading scheme in place through which emission reductions can be traded. Also, the DER market is still nascent and lack a competitive retail market for trading of distribution resources. The value added of the pilot was limited to testing existing institutional structures and capacity for registration, measurement of data, verification and certification.

Generating distributed energy resources (DERs) based on renewable energy sources has several advantages:

- It provides a secure and stable source of electricity generation at a low cost.
- It reduces electricity losses and peak demand.
- It has the potential of making a significant contribution to emissions reductions.

The scalability of distributed energy generation and the possibility of generating an environmental asset in the form of emissions reductions require the emergence of a market to facilitate trade across DER installations, sectors and, eventually, jurisdictions. One of the main challenges in creating such a market is the need to validate and consolidate trade in energy generation and emissions reductions among agents. Ensuring the integrity and cost-efficiency of trades requires sufficient market oversight to afford potential market participants certainty with respect to energy supply and emissions reductions. The transaction costs involved in verifying emissions reductions can be extremely high, especially when dealing with multiple trades across many small facilities.

The PTSP program ran from 2015 to 2019 and is expected to be renewed. During this period, it implemented 133 projects, with an investment of about $5 million, reaching about 5 MW of installed capacity.

The pilot was implemented in 10 public facilities selected from the 133 photovoltaic (PV) installations participating in the PTSP. Its objective was to test a blockchain-based system of certification for renewable DERs and emissions reductions. The project installed hardware and developed a blockchain algorithm designed especially for DER installations. The blockchain platform provided information from February 19, 2019 to August 30, 2019.

To validate data, the Public Solar Rooftop pilot initiative used a measurement system independent of the generation plant, which read multiple climatological variables, including solar irradiation. The data was then compared with what was reported on the monitoring platform of the generation plant. If both gave similar results, it was assumed that the information was correct and then emissions reductions were estimated.

Given the characteristics of the pilot, it was assumed that the plants displaced average energy from the grid, and not the last dispatched plant (that is, the PV self-generation was not enough to change the national energy mix), so the reduction was calculated as the amount of energy generated by the emission factor of the SEN (national electricity system).

Main attributes of the pilot are the following: (i) document the provenance of distributed solar PV generation; (ii) track emissions reductions achieved by of each unit of distributed PV generation system; and (iii) track ownership transfers between participants.

SETTING UP THE PILOT

Preparation and implementation of the pilot involved four steps, as described below.

Step 1: Install and operationalize data loggers

PTSP facilities record information on electricity generation data loggers that do not have a web-based network connection.[18] Independent inspection on the ground is therefore required to verify and certify these data, which is extremely costly. To address the problem, the pilot installed monitoring stations at 10 facilities to capture detailed real-time information on energy generation to determine emissions reductions. [19]

PhiNet data loggers are data acquisition systems programmed in Linux, Nginx, and NodeJS that capture relevant information on energy generation and consumption, as well as other control variables, such as temperature and radiation, which can independently verify generation data. The PhiNet stations generate blocks of data (on electric generation, radiation, and so forth), which are uploaded onto the web every 15 minutes (figure 4).

Figure 4

PhiNet data loggers and public solar roofs

Source: Phineal 2019.

The PhiNet stations generate more data than is strictly necessary. Data on radiation and temperature, for example, are useful for verifying the efficiency of the PV installation, but they are not needed to estimate reductions in greenhouse gas emissions. They were collected because one of the objectives of the project was to verify whether the electricity generation recorded on the registration platform currently operating the PTSP (Meteocontrol) was consistent with the PhiNet record and other control variables.

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[17] The program received support from the World Bank–managed Partnership for Market Readiness (PMR program).

[18] They are connected only to the central platform of Meteocontrol, the company that provides the centralized registration platform.

[19] Servers were programmed in Linux, Nginx, and NodeJS. Monitoring stations were PhiNet with GHI and connected directly with data logger blue-log.

Step 2: Program the blockchain structure

Phineal, the company that implemented the pilot project, developed a public, permissioned blockchain platform designed specifically to manage energy installations.[20] The platform, GTIME, identifies five data points relevant for energy management and the blockchain identifier. The blockchain platform records the following information:

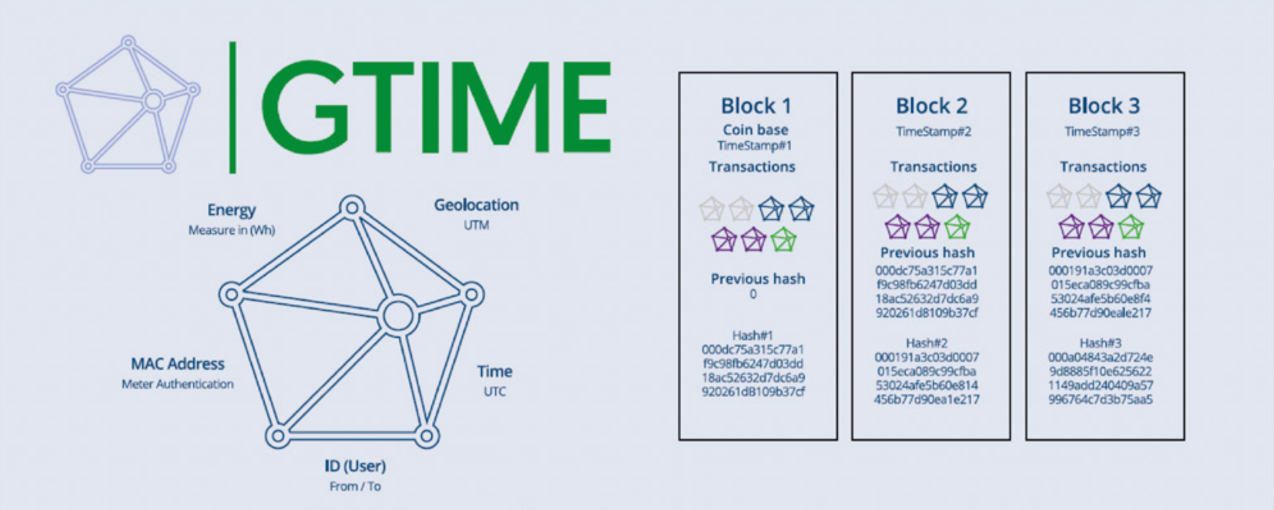
- Geolocation in Universal Transverse Mercator coordinates
- Time stamp using Coordinated Universal Time
- Environmental data (radiation and ambient temperature)
- Electricity generation (obtained from the billing meter or data acquisition system)
- Identification of the PV facility
- Media Access Control (MAC) address of the facility (unique identifier of the network device).

Every 15 minutes, the GTIME data block pulls energy and environmental data with a specific ID and time stamp from the PhiNet installation equipment.[21] It also provides a history of transactions—in this case, the energy injected into the network (Soto and Hermosilla 2019).

As the stations need 5 minutes to establish machine-to-machine communication over the Internet, every 20 minutes the PhiNet sends the data and generates the GTIME block, which is "stamped" sequentially in the chain, as shown in figure 5.

Figure 5

The GTIME blockchain



Source: Soto and Hermosilla 2019.

While this phase of the program did not register peer-to-peer transactions, trading could be programmed into a future iteration. This pilot captured only data on PV energy. Additional information could be included in the block for other sources of energy, such as wind patterns, or different types of data could be recorded and transferred (for example, a hash of images associated with reforestation projects).

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[20] The blockchain architecture is hybrid. Phineal can authorize other servers to operate as miners, but it did not do so. For a blockchain architecture to be hybrid or open, an Internet connection must be available.

[21] See https://gtime.io/.

Step 3: Operationalize the blockchain

Nodes within the GTIME blockchain were installed in public and private buildings throughout Santiago de Chile to capture data from data loggers. Nodes were required to have an Internet connection and a connection to the mainframe computer (both consuming less than 5W). After information is captured and stored on the blockchain, the information is made available to interested parties and the general public through a free-access website on which it is possible to visualize the generation of certified energy.

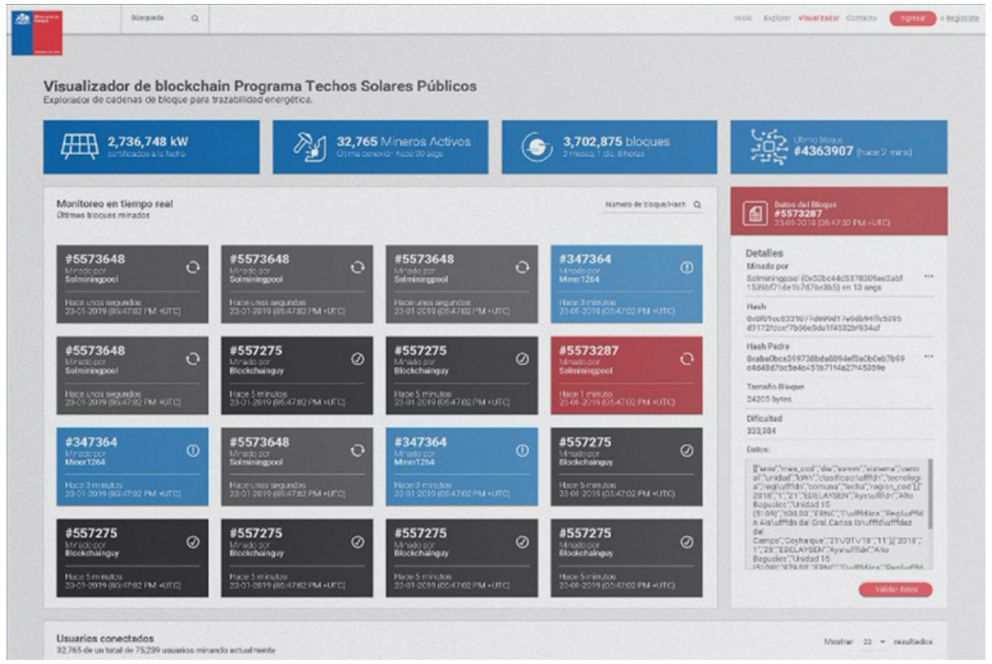
The GTIME blockchain is a dedicated (closed) blockchain network. Because Phineal is responsible for vetting each of the participating nodes (through a license that provides access to the network), only Phineal and government servers were allowed to participate. Phineal set up 10 dedicated servers to host the blockchain network. They were installed remotely and operated through the permissioned platform Phineal set up. The advantage of this approach is the ability to control participation and utilize a low-cost, low-energy consensus mechanism.[22] In this case, the only costs were for Phineal's proprietary programming and the initial investment associated with setting up the data miners.

Step 4: Construct a data visualizer

The last step is to construct a data visualizer, a centralized registry of the data blocks open to the public—or, in this case, to all participants—that presents the data mined from and verified across all installations in the network (figure 6). All the captured data are visible on this platform, allowing individuals to verify that the information is consistent with the original data loggers from the PTSP registration system.

Figure 6

Data visualizer



Source: http://gtime.io:4040/.

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[22] Data mining consumes energy. If the mining structure is public and open, an economic incentive must be put in place so that third-party servers can dedicate time and computer memory for mining. This is the approach taken by bitcoin, where mining activity is paid for with bitcoins for each puzzle solved or data block mined. In closed blockchains, the mining is carried out by dedicated servers. The advantage of this approach is that no additional payment for the actual mining is required; the only costs are the initial investment of acquiring and operating the servers and the energy cost of the mining. Which mining structure to adopt depends on the specific contractual arrangement the blockchain structure is trying to solve. In the case of this pilot, where the number of facilities was small and there was a role for government-regulated contracts, a hybrid blockchain was more appropriate, with Phineal giving permission for carrying out the mining.

COST OF THE PROJECT

The total cost of the pilot project was about $100,000 (table 1). But this figure does not give a clear picture of the actual or future costs of making this type of project replicable and scalable, for several reasons:

- Phineal donated its proprietary programming, which it had already created. Blockchain architecture is not expensive, but it does require programmers.
- The project involved actions and processes that are not necessary for verification, such as the PhiNet monitoring installations. 23
- Energy, technology, and programming costs are all falling.
- Phineal does not clearly separate its own sunk costs from its operating costs.

Table 1

Capital and variable costs of Chile's Public Solar Roofs Program

Item	Capital costs	Variable costs	Total cost
10 monitoring stations	PhiNet station (hardware with data loggers): $4,000	Installation and verification: $10,000 ($1,000 each)	$50,000
Blockchain installation	GTIME proprietary blockchain algorithm: 0 (Phineal had already developed the software)	Programming: 0	0
Blockchain management		Human resources: $10,000	$10,000
Miners (10 miners)	Purchase of 10 servers (20 others were already on hand): $500	5W of energy a day for three years: $500	$5,500
		Human resources: $10,000	$10,000
Visualizer	Dedicated line	Programming: $10,000	$10,000
Other administrative costs			$14,500
Total			$100,000

Source: Phineal 2019; communication with Eduardo Soto, head of the Phineal project.

No legal issues were assessed in the pilot. Similar projects in other sectors and countries could face legal hurdles.

5. RESULTS AND CONSIDERATIONS FOR SCALE-UP EMERGING FROM THE CHILE BLOCKCHAIN PILOT IN THE ENERGY SECTOR

The pilot provides a real-world example of the application of blockchain to the energy sector that could be replicated in other countries or sectors. It demonstrates that a blockchain platform can guarantee the integrity and transparency of the data and bring in participants from the public and private sectors. The project reduced emissions by about 800 tons of CO2 equivalent a year and saved about $250,000 in energy costs.

The project addressed three problems: measurement, registration, and verification.

The measurement problem.

The project set up its own web-based measuring systems, the PhiNet stations. However, any web-based stations that are standardized can be used. Distributed energy resource (DER) projects in Chile, including those participating in the PTSP, are not required to have a web-based generation metering system (smart meter). Yet web-based smart meters could be made a requirement in future applications, in order to track energy generation efficiently and collect the corresponding emissions reduction data. DER systems not equipped with smart meters will need ground-based inspection with independent verifiers.

The registration problem.

Establishing unique protocols for connecting new sources is necessary to register new facilities properly. The pilot has demonstrated the ease of establishing protocols for connecting new sources. PV facilities are identified using their Media Access Control (MAC) address. This is not a problem that blockchain resolves, but a good onboarding process can do the job. If the blockchain network encompasses many solar panels and sensors, then cloud technologies (such as an IoT hub) can be used to identify and monitor these devices.

The verification problem.

Blockchain infrastructure ensures the data has not been tampered with, thus facilitating the verification and allowing the certification of offsets. As the project continues or expands, a hybrid or even open source nonproprietary blockchain could be explored as the basis of verification. The Ministry of Energy's own Open Energy project may present a better alternative, as it is based on Ethereum, a well-known blockchain platform.

While the application of blockchain on climate markets remains nascent, lessons from the pilot, offered below, can help countries replicate and scale up similar projects to other sectors as they search for an integrated approach to energy transition and new carbon markets.

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[23] The PhiNet monitoring stations are not strictly necessary in the case of energy distribution, because the energy produced can be captured from a smart meter. The PhiNet monitoring station captured data on solar radiation and temperature; such data are needed to determine the efficiency of panels, but they are not necessary for verifying energy produced.

AN INTEGRATED APPROACH CAN HELP CREATE INCENTIVES FOR A MORE DECENTRALIZED ENERGY SYSTEM ABLE TO ABSORB MORE RENEWABLE ENERGY

The pilot helped strengthen and develop the market for small-scale renewable energy generation, which has had difficulties taking off, by creating additional incentives through the potential sale of climate assets. The Ministry of Energy has achieved much in terms of fostering large-scale renewable energy and pricing carbon for large-scale thermal boilers and turbines, but distributed generation development is lagging. Despite the advent of net billing (see box 3), the regulatory environment and business model are not yet conducive to a strong push for distributed energy.

The development of an MRV system to track production from renewables-based DERs, and the link to a potential climate registry, could help create additional incentives for small-scale renewable energy generators and the development of start-ups as business models. It has helped move the DER agenda forward in an innovative way by using new technologies and linking it to potential future climate markets.

The project also helped establish the conditions for a unique combination of private financing incentives for DERs with an innovative and well-designed public program and an MRV system, providing a practical application of the approach known as maximizing finance for development.

BLOCKCHAIN TECHNOLOGY ACTS AS AN ENABLER OF A WELL-DESIGNED BUSINESS MODEL

Benefits of using a blockchain architecture are numerous but scalability and replicability of this and similar pilots remain at challenge. The reason behind it lays less on the digital readiness of public or private entities, and more on the lack of functional business models. For instance, in the energy sector, implementation of smart meters (needed to be able to track transactions of DERs) has been a controversial issue in several countries because of the large up-front capital investments required for full-scale implementation throughout a country (these extra costs are often transfer to end users through electricity bills). However, a well-designed business model that links DERs transactions with the benefits of carbon trading could make the deployment of expensive smart meters profitable due to both selling of energy and climate assets. Therefore, blockchain technology acts as an enabler of a well-structured business model. Going forward it is crucial to think through the operational framework by linking sectors (i.e. bringing climate revenues to the energy sector, which generates approximately 70% of the greenhouse gas emissions worldwide) and identifying technology convergence (i.e. blockchain and smart metering).

BLOCKCHAIN TECHNOLOGY CAN CREATE A SECURE SYSTEM FOR COLLECTING AND TRANSFERRING ENERGY AND EMISSIONS WHILE REDUCING TRANSACTION COSTS

The project developed and generated a shared ledger system of relevant energy generation and emissions reduction data. The blockchain structure ensures that the transferred information from each facility is secure and provides a platform that can support a wide range of applications, including the trading of emissions reductions. Backed by a specific monitoring, reporting, and verification (MRV) system, the blockchain structure allows the Ministry of Energy to better track DERs.

Blockchain reduces the transaction costs of emissions trading by generating a viable and robust system that guarantees the integrity of climate asset information and makes those assets tradable. The project established a practical and cost-effective MRV system for energy mitigation actions tailored to the needs of Chile's energy sector, which could be expanded to include small-scale power producers.

Chile currently imposes a carbon tax of $5 per metric ton. Congress has recently approved a reform that allows facilities that want to reduce their carbon tax liability to do so by offsetting their emissions by paying a third party to reduce their emissions equivalent. Although technically possible, the high transaction costs of developing and verifying emissions reductions makes it highly unlikely that tax-liable facilities could offset emissions with the emissions reductions of small facilities, such as DER generators. However, a blockchain architecture such as the one proposed by this pilot could be the basis for a broad market in emissions offsets. A blockchain-based trading system, if well designed, could be both economically and technically viable. This blockchain-based trading system would allow facilities affected by the carbon tax to buy offsets from DER facilities, helping these facilities to meet the upfront costs of PV installations and credit subsequent emissions reductions to the facility, enabling it to reduce its carbon taxes. The blockchain structure is well suited as a supportive infrastructure for this scenario.

THE PILOT HELPED BUILD RELATIONSHIPS WITH GLOBAL INITIATIVES

The project strengthened collaboration between the World Bank and the Ministry of Energy on future climate markets under the Paris Agreement, according to the joint statement released April 11, 2019. The collaboration focuses on the development of mitigation outcomes, the World Bank Climate warehouse, and the piloting of blockchain technology. It provides an important example of supporting trade in climate assets registered through blockchain that could eventually build a Pacific Alliance Emissions Trading Scheme for Latin America and the Caribbean, which could serve as a model for middle-income countries in other countries. The project also provided a replicable innovative framework for generating climate assets and developing efficient market-based mechanisms capable of mobilizing additional finance to drive DER activities.

INTEGRATED ENERGY POLICY FRAMEWORKS

The pilot is implemented in a nascent market segment -distributed energy resources- that is set to grow substantially in the future (most notably in middle-income countries such as Chile). A combination of energy/digital technologies in fact will amplify the scope of DER markets. The “distributed” nature of this markets implies multiple transactions (between the prosumer/aggregator and the grid, and among consumers, or peer-to-peer). As of the date of this note, Chile has a net billing policy that rewards surplus energy injected to the grid at a fixed or regulated tariff. Under these conditions prosumers have no incentive to add battery energy storage (solar-plus-storage), since storing/shifting load is not rewarded by a peak tariff (for example, consuming stored solar energy during peak time would reduce the electricity bill for the prosumers, or storing solar energy for injections during peak time could be rewarded by a higher tariff). If peak tariff were allowed in Chile, solar-plus-storage would have a more strategic impact and higher benefit (i.e. more renewable energy and less emissions reductions) on the grid. Thus, in the future, recording and verifying these more complex transactions with blockchain will be even more important (or justifiable), since the potential for system benefits (deferring generation and network expansion and displacing fossil-fuel peakers) would be -in principle- substantially higher.

CONSIDERATIONS FOR SCALE-UP

Chile’s experience can provide relevant lessons to other countries exploring the using of blockchain to support climate markets. Blockchain could also contribute to the decarbonization goals and climate markets strategy of the country. However, there are some key considerations that the government of Chile could assess further to scale up the use of blockchain on climate and energy markets.

Additional testing.

The Public Solar Rooftop program provided relevant insight on the potential of blockchain for the energy sector, but further testing is needed to understand the full potential of the technology and assess the challenges. The potential to support the country’s climate strategy will depend on different criteria and the decision to implement a blockchain approach should be based on a thorough evaluation of different factors, such as:

- Cost benefit analysis: further analysis is needed to understand the benefits of blockchain application compared to different technologies, and what are the costs associated to running and maintaining a blockchain-based system.
- Governance: the decentralized nature of blockchain requires a good understanding of the governance options and of the stakeholders that should be involved in the process.
- Regulatory framework: given the rapidly evolving landscape of blockchain technology, it will be important to consider how to comply with rules related to the data managed on the blockchain system.
- Interconnection with climate policy instrument and tools: Additional testing should evaluate the feasibility of interconnection with national systems and tools, and how the connection would work given system requirements such as documentation, support tools, and permissions.

Cross jurisdiction interconnections.

Given the transparent and decentralized nature of blockchain, the technology could support the development of cross-country linkage. One of the main potentials of blockchain is its ability to connect decentralized systems and help securely track assets across different systems and avoid double counting. This could provide critical benefits for cross-country linkages since connecting diverse market mechanisms through a decentralized, blockchain-based approach could potentially be simpler and more cost-effective, in comparison to a centralized approach. Blockchain technology could allow instant comparison of reliable data across national and sub-national jurisdictions. The experience and lessons learned by the Government of Chile through this program could serve as a starting point for regional coordination and collaborative testing in future years. Other countries in Latin America such as Peru, Colombia, and México are already implementing carbon pricing instruments and could potentially benefit of the application of blockchain technology.

CONCLUSION

Technology can help countries achieve a successful energy transition and meet the ambitious commitments set out in the Paris Agreement. Thanks to new technologies, standardized protocols, rules, and structured certification systems, the costs of monitoring and reporting progress toward commitments are falling. But authorities must still deal with the coordination problem associated with centralized accounting and registration systems, as well as verifying energy generation and emissions reductions, both of which involve considerable costs.

These costs can be particularly high when there are many small facilities, such as renewables-based distributed energy projects. For prosumers and carbon emission markets to be viable in such settings, a cost-effective system for verifying energy and emissions is required. In parallel, dealing with climate change mitigation implies significant global costs. The World Bank estimates that global integrated carbon markets could potentially reduce mitigation costs by 54 percent in 2050, or approximately $3.94 trillion (World Bank 2016). These costs can be reduced by creating greenhouse gas where mitigation abatement costs are as low as possible, which in turn requires the development of energy and carbon markets.

However, the transaction costs associated with the development of these markets can be extremely high. Their emergence requires an institutional infrastructure that can support the coordination of multiple agents and ensure information security, verify energy and emissions reductions, and register energy and emission trades across different countries and legal systems. Lack of such an infrastructure is one of the principal problems stymying the emergence of integrated energy and carbon markets across the world.

Blockchain technology may provide a solution. A blockchain-based architecture can accommodate data that are captured automatically to support an integrated network of energy and climate markets over time. Furthermore, as the pilot project in Chile shows, although initially complex, blockchain does not require a sophisticated information technology infrastructure. This key disruptive technology, if coupled with a well-designed governance structure and converged with other technologies, could facilitate the development of markets by supporting transactions of all types of energy and emission-related data (facility-level, projects, programs, quantified production, life-cycle attributes) in a shared, globally accessible environment, at low cost.

Chile taxes carbon at a rate of $5 per metric ton, and a new tax bill has approved a reform to allow for an offsetting scheme—thus providing the basis for a carbon market. Facilities that must pay the tax can reduce their tax liability if they can show equivalent reductions elsewhere. However, the high transaction costs associated with emissions trading across small facilities that can reduce emissions, such as distributed energy generators, makes it unlikely that they will become viable market participants. For such trades to be possible, a central authority must register them and account for the energy generated and/or emissions reduced. Doing so is relatively simple for large facilities but very costly in for small ones. By reducing the transaction costs associated with registering trades from small facilities, blockchain may open an immense new market of energy and emissions reductions and generate the upfront investment in distributed energy installations, while having a direct impact on small and medium-size firms, local communities, households, and sustainable consumption practices such as public transport and cycling.

Addressing the transformational energy transition and climate change threats will require the application of diverse and innovative solutions and approaches. Mitigation implies enormous economic costs. Integrated carbon and energy markets support mitigation while reducing overall transaction costs. Blockchain may be just the right technology to facilitate the emergence of the institutional and governance structure necessary to develop and bring together synergies in carbon markets and the ongoing energy transition, at both the local and global levels.

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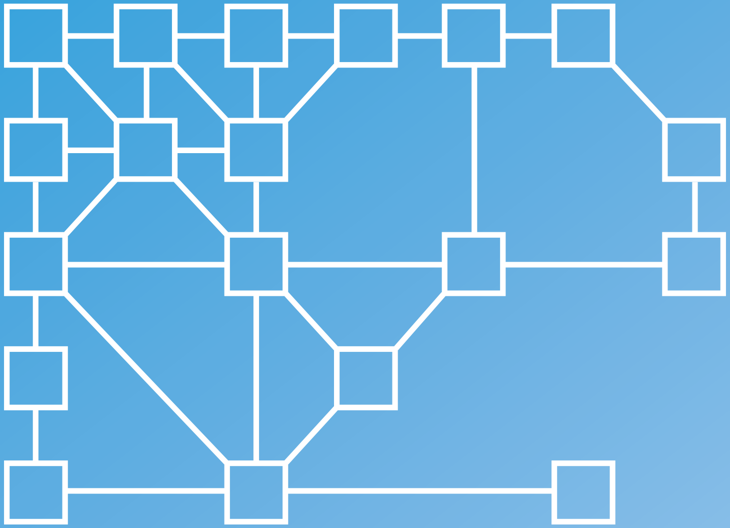

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December 2020

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