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Florence School of Regulation

Blockchain meets Energy

Digital Solutions for a Decentralized and Decarbonized Sector

Imprint

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Contents

Acronyms

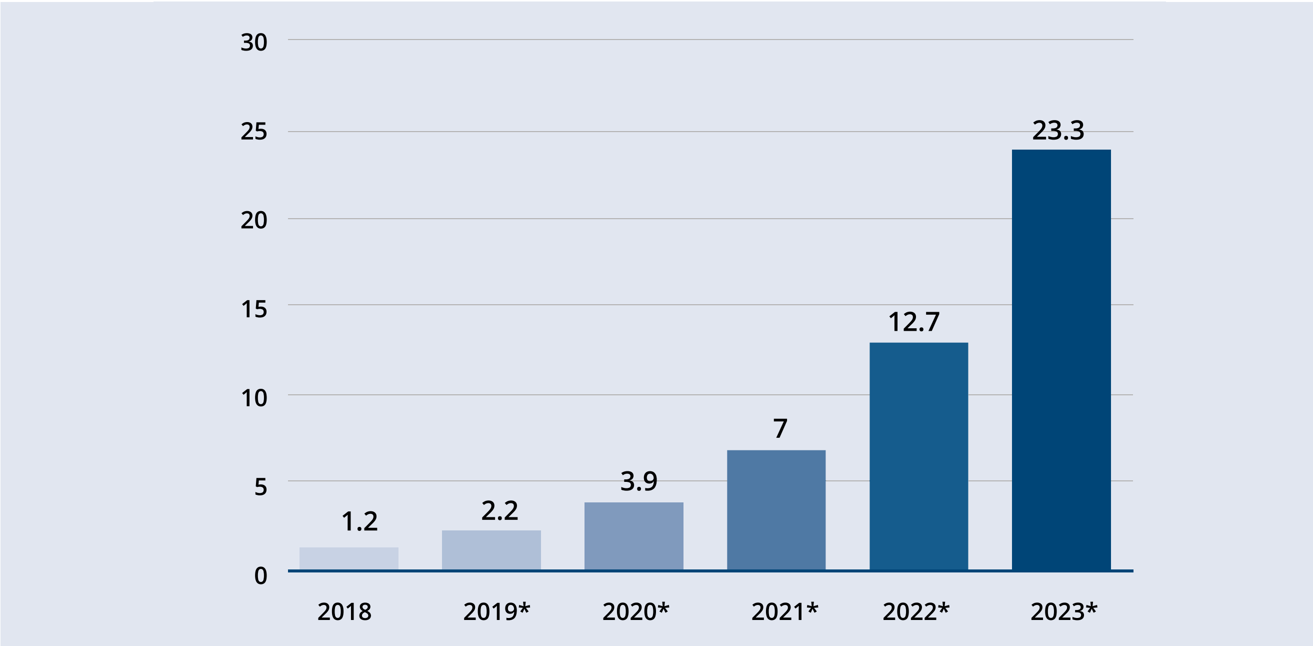
AI	Artificial intelligence
AIE	Electricity and Electronics Industry Association (Chile)
API	Application programming interfaces
Banxico	Mexico's Central Bank
CEC	Clean energy certificates
CFE	Federal Electricity Commission (Mexico)
CNBV	National Banking and Securities Commission (Mexico)
CNE	National Energy Commission (Chile)
CoDi	*Cobro Digital* (Mexico)
CRE	Energy Regulatory Commission (Mexico)
dApps	Decentralized apps
DER	Distributed energy resources
DLT	Distributed Ledger Technology
DSR	Demand-Side Response
EP	German-Mexican Energy Partnership
EU	European Union
EVs	Electric vehicles
FSR	Florence School of Regulation
GHG	Greenhouse gas
GW	Gigawatt
IDB	Inter-American Development Bank
IoT	Internet of Things
IT	Information Technology
kW	Kilowatt
kWh	Kilowatt hour
M2M	Machine to machine
MW	Megawatt
MWh	Megawatt hour
P2P	Peer-to-peer
PoAu	Proof-of-authority
PoS	Proof-of-stake
PoW	Proof-of-work
PV	Photovoltaic
SDGs	United Nations Sustainable Development Goals
SEN	National Electric System (Chile)
SENER	Ministry of Energy (Mexico)
TWh	Terawatt hour
USD	United States Dollars
vRES	Variable renewable energy sources
Wh	Watts hour

Foreword EP

The global market for blockchain technology was at only 1.2 billion USD in 2018. Still, the hype is high when it comes to "blockchain" – a technology which has gained a lot of attention. From governments to start-ups, from utilities to academia and civil society organizations – all are stepping into a digital era in which blockchain is best known by cryptocurrencies like Bitcoin. But blockchain is much more than cryptocurrencies. Blockchain, a distributed ledger technology (DLT), offers many possible uses to governments, society at large and businesses spanning across different areas: inter-company transactions, taxation, supply chain management, peer-to-peer trading (P2P), Internet of Things (IoT), Demand-Side Response (DSR), carbon - offset trading, just to name a few.

Global revenues of blockchain technology is forecasted to have significant growth in the coming years, being expected to climb to more than 23 billion USD in 2023. The largest share will come from the financial sector, closely followed by the energy sector.

Size of the global blockchain technology market 2018-2023 (billion USD)



Source: Statista, 2018

However, it is not just the potential economic impact that makes DLT so interesting, it is because a number of existing blockchain applications have demonstrated direct or indirect impact on the achievement the United Nations Sustainable Development Goals (SDGs). This is a key factor for international cooperation.

In that sense, the EP provides insights about and, if beneficial, support for DLT use cases in the energy sector. An energy sector that is rapidly changing from an analog world of a highly centralized, fossil fuel-based generation and transmission system to a new paradigm of decarbonization, decentralization, and digitalization (3D´s). New challenges within a future electric system will be defined by a high percentage of renewables and customer-sited smart technologies, such as rooftop solar, behind-the-meter energy storage, electric vehicles, smart thermostats and more. In a world with residential prosumers, distributed energy resources (DER), digital technologies and increasing shares of renewables, especially utilities, system operators and regulators are left with new tasks.

Together with key energy sector stakeholders we organized an international experts' event on "Blockchain meets Energy"[1], which shed light on possible and already implemented blockchain applications. Impressive international use cases were outlined: public service operations; certification and tracking schemes; distributed and microgrid solutions; IoT; as well as free,

[1] "Leveraging digitalization – Blockchain meets Energy - Workshop on blockchains in the electricity sector" Mexico City, November 14th & 15th, 2018.

open-source scalable blockchain platforms specifically designed for the energy sector's regulatory, operational, and market needs.

Now we are partnering with the renowned FSR to make some of those insights known to an even wider audience. It should help to get a better understanding of what DLT are and what they are not; what their potentials and what already existing applications are. This is extremely important, because while the pro-blockchain community argues that it will be nothing less than a revolution to the fabric of our society and economy, skeptics see it as an overblown hype pointing towards existing solutions such as clouds, cryptography or simple databases.

But what if we see blockchain as a solution to the 3D energy world of the 21st century, rather than a disruption itself? "When we do, we can seize the possibilities blockchain offers: a way to make a decentralized electricity grid more secure against cyberattack by eliminating vulnerable, centralized single points of failure; a way for millions—and eventually, billions—of DERs to connect, verify, and transact with one another; a way for the green attributes associated with renewable energy to be tracked and traded with unprecedented levels of transparency and automation, streamlining costs and enabling greater market participation; a way for electric vehicles (EVs) to become cooperative and interactive grid assets, rather than `dumb´ sources of spiking grid demand that exceed circuit capacities" (Bronski, 2019).

Enjoy the reading!

Josche Muth
Coordinator of the Secretariat of the German-Mexican Energy Partnership

Foreword FSR

The FSR partners with the EP. Why?

Because understanding "blockchain", its nature and potential, has become a duty for a school like us, offering an energy policy and regulatory knowledge hub to both energy practitioners and academia. Giving a neutral access to the facts and to the truth, in a world of continuously twisted information by particular interests, strategic lies and fake news, or sincere misunderstanding and consequential ignorance, is a core duty of the FSR.

In November 2018, FSR took part in the honest and incredibly valuable "Blockchain meets Energy" workshop in Mexico, organized by the German-Mexican EP, and thought it would be of the highest interest for our audience, either in Europe or worldwide, to get access to the high-level exchanges among its many participants, from the Americas or Europe.

Here it is.

Victor Peter (GIZ Blockchain Lab) introduces the mattewr by explaining, in really simple words, what blockchain is and is not; the numerous types of variants it can give birth to, notably the "public" and the "private"; what is the best use of each variant; and why not to use blockchain when traditional tools, as simple data base, are better.

#Juan Paredes, from the Inter-American Development Bank, provides a nice transition between Victor's blockchain introduction and the coming contributions applied to Mexico and Chile. Juan shows why blockchain has a very special and crucial role to play to accelerate energy transition by simplifying decentralized transactions and securing identification and measurement. Blockchain is an enabling technology that can empower many new players entering in a deep 'energy paradigm shift' linking digitalisation to decarbonation via decentralisation.

Moisés Rosado Rivial (Global Grid) reviews the opportunities for blockchain in the Mexican renewable energy market. Creation of prosumer-centered market places; use of automated smart contracts to build crowdfunding platforms feeding solar projects; issuing and following up clean energy certificates (CEC) nurturing a traceable exchange.

Eduardo Soto Sepulveda and Diego A. Hermosilla Astorga (Phineal) describe the development of an electricity traceability frame where blockchain technology permits to identify and measure individual electricity injections and withdrawals, to calculate every 15 minutes the losses incurred, and to feed an automated smart contract settlement and payment for green electricity.

As you can see, and as we use to say at FSR, technology enables and does not dictate what to do with it.

Blockchain technology is decentralization friendly and permits many novelties that were only dreams 10 years ago. Which ones? Innovators, projects and pilots will test and tell. Innovations like the ones discussed from Mexico and Chile also show that the 21st digital century will be made by the humans investing in it. And that leapfrogging North America or "Old Europe" is always doable: only a matter of will, efforts, consistency, time, and sense of opportunity.

Jean-Michel Glachant
Loyola de Palacio Chair holder & Director Florence School of Regulation (European University Institute)

1. Blockchain in the energy sector – An introduction to the technology and its potentials

Viktor Peter
GIZ Blockchain Lab

I. Abstract

The digitalization of the energy industry is continuing to gain momentum. Blockchain[2] technology, which can bring far-reaching changes in the energy sector, is currently emerging as a new driver of this rapid development. Blockchains are a special kind of data management system that identifies and tracks changes (transactions) within the system digitally and shares this information with the distributed computers connected to the network. These computers check and add new entries (transactions) into the ledger if proven correct by the majority of the computers connected to the system. Cryptographic encryption, transparency and economic incentives keep any malicious computer from entering wrong new entries.

Blockchains have the potential to optimize energy management processes in almost all stages of the value chain and at the same time to cope with the growing complexity in the increasingly decentralized energy system. Even if the general conditions for blockchain projects are very different in the international context, the basic application possibilities are similar. In order to really be able to use the actual added value of the technology, however, it is necessary to consider fundamentally new, decentralized structures – towards a blockchain thinking.

II. Key words

DLT, blockchain, energy, certificate, wholesale, trading

III. The transformation of the energy industry

The energy industry is currently undergoing a double transformation: in addition to the energy transition towards renewables, digitalization is changing the basis of the value creation in the sector. With blockchain, the energy industry is also obtaining a new promising technology that is currently on everyone's lips. Experts assume a potential for innovation and change comparable to the triumph of the Internet. The development of ever new applications based on blockchain technology and numerous projects by energy suppliers underline the high dynamics and the associated expectations.

IV. About blockchain

What the blockchain is not

At the latest since the rapid rise of the cryptocurrencies, like Bitcoin or Ether, the topic blockchain has also moved into the focus of media reporting. In many cases, however, the functionality and properties of the blockchain technology are shortened considerably or incompletely reported. Therefore, as a first step it makes sense to understand what the blockchain is not.

A blockchain is not the "one" blockchain. There are several hundred different blockchains, which differ in their decentralization, their consensus mechanism or their access. In addition, the majority of blockchains run completely autonomously from other blockchains, which means that different blockchains cannot communicate with each other, i.e. they cannot exchange data.

Blockchain is not Bitcoin and Bitcoin is not equal to blockchain. Bitcoin is a cryptocurrency that uses blockchain as its technological base. It is therefore an application on a blockchain, but by far not the only conceivable application scenario. In addition, it is of course not the only crypto currency: there are more than a thousand of them. And a blockchain does not necessarily need a currency, especially private blockchains often do not use a crypto currency. In public blockchains, on the other hand, these currencies serve as an incentive mechanism to attract more participants and to reward correct behavior or the provision of computing power within the blockchain with "monetary" values.

A blockchain is not the same as a database. One of the central strengths of the blockchain is its decentralization,

[2] Blockchains are a kind of DLT. A DLT does not have to be a blockchain, though. In the following, however, the terms are used synonymously.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which also distinguishes it from traditional databases. With classical ledgers, the security challenges are growing as more participants have the right to change data records. With a (public) blockchain, on the other hand, more participants provide increasing security because they check each other in consensus for the correctness of new data entries.

Blockchains are also not a standalone-solution. Only in combination with other digital technologies can blockchains generate a high added value as a trustworthy infrastructure. An example from the energy sector could illustrate this statement: generation facilities such as PV rooftop units can document the quantity of the electricity generated directly into a blockchain through a terminal device connected to the Internet. This provides tamperproof documentation of any electricity fed in or consumed. However, it is critical to ensure that the devices that enter data into the blockchain are set correctly. Plausibility checks, i.e. data analytics, can also help to identify incorrect sources of information. Otherwise, there is a danger that incorrect data will be written into a blockchain that does not capture actual conditions. In Information Technology (IT), this is also referred to as the "garbage in, garbage out" problem.

What the blockchain is

In general, and in very simplified terms, a blockchain is a growing file that contains all the transactions (data entries) that have ever been entered on it. However, this file is not stored on a central server, but on the computers of all participating players. New transactions, i.e. data entries, are added by consensus in an automated approval process between the participating computers. For this, the majority of the "votes" of the connected computers in the blockchain network is needed.

This mode of operation gives origin to two central innovative properties that have been made possible by blockchains. First, there is the issue of data sovereignty, i.e. the user control over data that is released. Blockchain technology has made it possible to make data records (about currencies, image rights, but also kWh) on the Internet unique and non-copiable. This also goes hand in hand with the transparency on which the technology is based: because everyone has the same data set, it is always possible to see who is holding which good. Of course, there is no need to provide the real name of a participant in the system for this. Changes in possession are located in a wallet, a digital account book, that is just a string of numbers and that does not provide the name of the owner.

The second big novelty that blockchains bring with them is their ability to create trust for actors who do not (have to) know each other. With this technology, it has been possible for the first time to replace central actors such as banks. Because technology creates the trust and functionality that was previously ensured by these central institutions.

Development of the technology

The Bitcoin blockchain is the world's first blockchain to run since 2009. It and its clones – the code is open source and has been used with modifications in other blockchains – are considered first generation blockchains. The transactions within these blockchains are primarily designed for the exchange of financial assets. In these blockchains, any person or company under a pseudonym (wallet number, similar to a bank account number) could and can take over any role within the system without prior verification. Popular examples of this generation are Bitcoin, Litecoin and Dogecoin.

With the second blockchain generation, primarily driven by Ethereum, intelligence, applications and automation were introduced into the blockchain space. This allows information, "self-executing contracts" (smart contracts) and complete software programs (decentralized apps, dApps) to be operated in the blockchain. Thus, the representation and transaction within the blockchain is no longer limited to financial assets. Rather, any information can be displayed and transferred, such as certificates, image rights, shares or even electricity deliveries.

The latest developments are moving further and further away from the principle of a blockchain, in which several hundred individual transactions are packed into one block and chained to the previous block. The background to this approach were considerations of velocity of the whole process. If a global network of computers has to check every single transaction and not a bundled number of transactions (in a block), the verification of entries takes far too long. For example, in the Bitcoin blockchain, a new block with around 1000 transactions is created every 10 minutes. If only one transaction were verified every 10 minutes, the procedure would be much too slow and inefficient. However, new technological developments can now circumvent this problem and enable individual transactions to be displayed in a DLT without the virtual creation of blocks. As a result, speed and scalability might increase with no transaction costs involved.

One representative of these new approaches is IOTA[3] with its concept of the tangle. Put simply, the principle of this approach is based on the following: if you want to make one transaction, you have to confirm two transactions that have not yet been confirmed by the attached network of computers. The technology behind IOTA promises to be used as an operating system in the IoT. Among other

[3] The IOTA protocol is a distributed ledger technology developed by the IOTA Foundation.

things, it should make it possible for machines not only to communicate with each other, but also to automatically pay for services. An example would be an electric car that agrees with a charging station on a price for a charge and pays via IOTA, while recording on the ledger what quantities have actually been charged.

Different access, different blockchain, different business models

As already mentioned, there is not "one" blockchain. Many types of blockchain coexist, all with their specific characteristics. Therefore, each type of blockchain has its own set of particular advantages and disadvantages and is suitable for different applications. Regardless of their technical differences, the following statement can be made for each blockchain: a distributed system which provides a tamperproof log that records all changes.

One crucial aspect in categorizing blockchains is how access to them is managed. A distinction is generally drawn between public (permissionless) and private (permissioned) blockchains. Hybrid solutions are known as consortium (shared permissioned) blockchains. Today's most popular blockchains, such as Ethereum or Bitcoin, are "permissionless," in other words, public. Anyone can participate in the blockchain with his or her computer and mobile devices. Public blockchains are based mainly on the proof-of-work (PoW) consensus mechanism to add new data entries in the ledger. Or to frame it differently: for creating new data blocks. In this consent mechanism, the computers involved deliver more or less a PoW undertaken to generate a new block. Public blockchains currently have considerable technical limitations, especially in terms of speed. Unrestricted access and governance issues also prevent some corporations from using this kind of blockchain. However, public blockchains are highly secure thanks to their architecture and number of participants. And participating in a public blockchain is relatively easy and involves low initial investment.

With private (permissioned) blockchains, the access of participants to the blockchain can be managed by a central authority. Accordingly, the consensus mechanism can be structured differently. Generating new blocks or single transactions is handled using the resource-saving proof-of-authority (PoAu) approach, where a single, previously specified or randomly picked participant (authority) generates new data blocks. Private blockchains are, by definition, limited when it comes to expansion, because actors must be picked or fulfil some specifications to be added to the network. However, this enables applications to be developed and used very quickly, as the partners are known in private blockchains. Yet, the high level of efficiency in private blockchains also means that the number of connected computers that must be attacked during manipulation attempts is smaller than in public blockchains. Establishing and operating proprietary private blockchains or licensing models also entails specific investments with a correspondingly greater financial risk than using existing (open source) solutions. Private blockchains are well suited not only for use with in-house processes designed for high data throughput, for example, but also for applications requiring a high level of trustworthy transparency for different actors, which can be ensured by the blockchain. Consortium blockchains are, as semiprivate blockchains (shared permissioned blockchains), a compromise between public blockchains and private blockchains. Consortium blockchains are limited with regard to the extent to which they can be scaled up: both the participating computers and the authorized applications require the approval of the entire consortium. On the other hand, this kind of approval, subject to checks, is very attractive for companies. Consortium blockchains will have to show how this can be combined with the counteractive limitations on expansion by focusing on specific individual applications on the one hand, and on the goal of achieving high appeal through the reach of the platform approach on the other. Some experts currently predict a promising future for the hybrid forms consisting of different blockchain types.

The three blockchain categories offer associated advantages and disadvantages and are, therefore, ideally suited for different applications in the energy sector. It is crucial to understand which type of blockchain fits which specific process, model, or service.

In the future, the importance of interoperability between different blockchains (public, private, and consortium) is set to rise. It is also becoming increasingly useful to link blockchains from different sectors (energy, banking, insurance, health, and automotive industries, for example). Achieving this interoperability is regarded as one of the key success factors for blockchain technology.

In which scenarios does blockchain show its special value?

The question of whether a blockchain makes sense for an energy industry application is often not a technical one at all. Rather, a closer look at the specific application scenario with its economic, regulatory and ultimately non-digital technological challenges is the necessary first step. Only then it is possible to clarify whether blockchain technology offers added value in new projects and, if so, which one.

This calls for completely new approaches in order to fully exploit the advantages of a decentralized, tamper-proof database. If, on the contrary, known solution models are used for existing problems and the blockchain is only


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squeezed into existing systems, the full potential of the technology may be wasted. Such projects deliver little added value and, especially in competition with existing systems, such as classical databases, do not always have an advantage.

A blockchain-based solution is advisable if there is a need for an identical database with a large number of participants pursuing different interests. If there is further need for common participation rules, the documentation should be transparent and unchangeable and if the transaction rules do not change constantly, a blockchain solution makes sense.

If, on the other hand, a limited number of known participants are to use a common database, or if other points mentioned above do not apply, a classical, central database can also be the best solution. The use of a blockchain or DLT in general and related investments should then be well considered or at least open other business opportunities.

Applications for the energy sector

One can assume that after the financial sector, energy will be another sector that blockchains will massively change. In the financial sector, the blockchain has the characteristic that it can potentially replace central trust bodies such as banks or insurance companies, which have hitherto played a decisive role within the system: trust is created through technology. In the energy industry a different advantage of the technology comes into. The increasingly decentralized and digitally connected energy system needs a secure IT-solution for communication, automation and documentation. A well-functioning energy system is dependent on data being shared correctly, quickly and uniquely with the relevant actors within the system. Therefore, it is crucial how large data streams from decentralized electricity feed-in, smart metering or grid operation can be managed. Blockchains promise a more efficient and resilient IT-infrastructure in comparison to existing systems to manage aforementioned data in distributed electricity systems, while allowing for a new level of transparency, tamper resistance and security.

In addition, households and companies are increasingly moving into the focus of the global energy system as individual market participants, as they are participating more and more actively in the market via small-scale interactions. Blockchain and other DLTs can play to their strengths here, as they are particularly suitable for decentralized systems with a large number of actuators. A secure data basis also makes it possible to improve the use of power grids, as this allows for better integration of flexibility resources. The ability of a (private) blockchain to map even the smallest transactions in an economically efficient manner means ultimately new degrees of freedom for the entire sector; for example, for the provision of balancing energy, for direct electricity trading between private market participants and also for shared investments. Accordingly, pilot projects on a blockchain basis are currently found in all areas of the energy value chain.

At the moment, two particular use cases seem to be focused by many players as they appear to be the low hanging fruits for blockchain applications: green electricity certificates and electricity wholesale trading. The prerequisite, for both green energy certificates as well as electricity trading, is that the participating electricity generators have installed smart meters that communicate via the Internet. They provide data on the quantity and price of the energy transmitted for trading issues or create a certificate for green energy production. The information about these events can then be stored on the blockchain. Therefore, both models cannot be implemented without digital hardware that bears the corresponding costs. Both cases rely on smart meters and smart contracts: potential transactions are carried out based on smart contracts, while smart meters provide the data for them. In these contracts, the parties agree when they will trade electricity or certificates at what price and how the energy or the certificate will be paid.

Green electricity certificates promise incentive mechanisms for the production of electricity based on sustainable energy sources. With the blockchain technology, these certificates could be issued uniquely. The certificates can be designed to be tradable and priced accordingly – either on market mechanisms or initially at fixed prices with guaranteed purchases by governmental actors. This would lead to incentives to invest more in these renewable energies and would also make a completely new product possible. As an indirect effect, CO_2 emissions could be reduced, and a higher supply of electricity ensured.

Electricity marketplaces are heavily dependent on data integrity. In a blockchain-based scenario, it is vital to collect data streams from decentralized electricity feed-in. Validity of this data is best ensured by using tamper-proof cryptography-enabled hardware as well as an algorithm cross-checking various data sources against each other. Based on such validated data sources, a blockchain-based electricity marketplace cannot only match the demand and supply side for energy purchases, but also immediately settle the transactions, including monitoring the delivery of electricity and processing of corresponding payments. Smart contracts can ensure that electricity is requested, for example, when prices fall below a price threshold or when green electricity or local power is available. The advantages of blockchain open up considerable positive consequences. (Wholesale) trading based on blockchains would allow for new incentives to invest and operate renewable electricity generation by providing a highly automated and yet secure way to buy and sell electricity. Blockchain technology promises direct, anonymous trading of various products in the electricity market without the need to involve a marketplace or intermediary, thus saving the relative costs of an intermediary. This is mainly because blockchains enable trustworthy transactions between players who do not know or trust each other. Particularly in countries that do not yet have energy trading systems, completely new markets could be created, and far-reaching investments could be made. The consequences for the consumer would be greater security of supply, but also the possibility of incentivizing own renewable energy generation and directly benefiting from their investments.

V. Conclusion and outlook

Blockchain technology is developing rapidly. Frequently cited weaknesses, such as high energy consumption or low transaction speeds, are being addressed by technological advances such as proof-of-stake (PoS), zero-knowledge proofs and sharding.

An ideal implementation context for blockchain application in the energy sector is primarily dependent on the regulatory conditions in the respective country. The issuing of green electricity certificates based on blockchains, for example, is usually not prohibited. But certificates only bring added value if they are also accepted by corresponding regulatory bodies. They must ensure under what circumstances these certificates can be traded and provide an enabling legal framework. The regulatory authorities therefore have a correspondingly important role to play: they must create a legal basis for the recognition of these certificates and, if necessary, create markets that are suitable for trading.

For energy trading on blockchain, the regulatory hurdles often appear to be higher. If, for example, there is only one state-owned company, new actors to the market need to be allowed to join. Also, other factors play a role, such as whether electricity should only be traded to stabilize the grid or whether it should also be traded for profit. This is not a technological but clearly a regulatory decision. As with certificates, the regulator has an important role to play in creating an ideal implementation context. Since high potentials are to be expected in both cases, also for the regulator, a regulatory adjustment cannot be ruled out. However, this would take a correspondingly long time. Regulatory sandboxes would be an attractive alternative that would make it possible to test the cases. In these locally and temporarily restricted areas, suitable cases could be tested with blockchains.

The possibility of providing a secure system for communication, automation and documentation with the blockchain is particularly interesting for the energy industry. In the medium term, the energy industry will therefore focus on applications for automation and documentation processes. They can become the basis for new digital business models. Predictions about the future, however, do not seem particularly reliable now due to the nascent nature of the technology.

Most of the projects are currently at an early stage with limited maturity. Although many blockchain applications may add different values to electricity systems, the jury is still out.

2. Digital innovation for a 100% renewable energy world

Juan Roberto Paredes
InterAmerican Development Bank

I. Abstract

Considering the urgent decarbonization needs of society, associated with the digitalization and decentralization trends experienced in the power sector in recent years, DLTs, have the potential to facilitate new forms of interaction between energy sector players and provide benefits along the electricity supply chain. The results from ongoing pilots are providing valuable lessons in terms of efficiency improvement, increased transparency and monitoring of electricity transactions and flows. The role of electricity consumers will be fundamental to a rapid shift to more sustainable forms of energy, therefore DLTs have also the potential to empower energy users to participate more actively in the energy transition. This contribution describes the challenges of integrating variable renewable energy sources (vRES), such as wind or solar, into power system operations and how DLTs could contribute to a better management of the power system. It also outlines potential short-term applications for blockchain, a type of DLT, and some of the use cases already implemented in Latin America.

II. Key words

Energy transition, blockchain, renewable energy, sustainability

III. Digitalization of the electricity systems

The energy transition is still far from being a reality. The outlook could not be more disappointing: the rate at which energy demand increased in 2018 was almost double the average growth since 2010 (IEA, 2019a). This fact per se should not be considered negative from an environmental point of view however, 70% of the fuels we used to cover that additional demand in the last two years have come from fossil sources that are causing the same problem we want to solve with the energy transition. The fuel that covered the largest percentage of energy demand in 2018 was natural gas at 45% (IEA, 2019a). Combined with coal and oil, these three fossil fuels were responsible for the majority of the increase in atmospheric CO_2 emissions recorded in the last 50 years (CDIAC, 2017).

Unfortunately, in the power sector, the situation is not that different. Even though renewable energies covered 45% (IEA, 2019a) of the additional electricity demand in 2018, they were not enough to cover the largest increase in electricity demand of the last eight years. Therefore, more natural gas and coal were needed to generate electricity, which led to the consequent increase in carbon emissions (IEA, 2019a). These had been stabilizing in the period from 2014 to 2016, but in the last two years the trend has reversed again upwards, moving significantly away from the path we should follow to proactively prevent a global warming of more than 2 degrees Celsius, in accordance with the commitment signed by 197 countries under the Paris Accord. We must remember that net carbon emissions must reach zero by 2050 in order to keep us on such a path.

In short, there seems to be a clear disconnect between achieving decarbonization of the planet and the reality of the energy sector. We should not deny the great advances of wind and solar energy, which have already prevented a significantly more pronounced growth in emissions and the rise in global temperature. However, the predominant feeling is that in order to avoid the greater impacts of the climate crisis that we are already experiencing and which the new generations so eloquently remind us of, we must multiply our efforts and accelerate the energy transition on all possible fronts.

It is not just a matter of changing the fuel to generate our energy in a more sustainable way, but also a matter of changing the way we consume, produce, and trade it and thus achieving greater efficiency and sustainability in the use of resources. Therefore, one of the priorities should be to implement a fundamental paradigm shift in energy markets and the way electricity systems are managed. The current paradigm is characterized by a centralized system where electricity flows in a single direction from large generation plants to consumers, who traditionally have had a passive role and have not been able to intervene directly in decisions, regarding how electricity is produced

or how the electricity they receive in their homes, industries, and businesses is managed.

Added to this, there is the possibility that former consumers can also produce their own energy through distributed generation which reverses the traditional flow of electricity in the electricity grids. This enables them to take a much more active role. The problem that arises is that the power system was never designed with the concept of decentralization in mind. The electricity market is based on one-way large-scale wholesale transactions between a few intermediaries, which will surely need modifications to adapt to the new context of the innovation, sustainability, and urgency of the energy transition demanded by society.

This is where digitization can make a decisive contribution to achieving the goal of decarbonization and strengthening the decentralization of the electricity system. What cannot be measured cannot be changed. But many inefficiencies in electricity generation, transmission, and distribution have gradually been reduced by the introduction of "smart" metering along the entire electricity supply chain. However, the smart thing about metering is not the data itself, but what we can do with it to increase the efficiency of the system. Thanks to tools such as artificial intelligence and machine learning, it is now possible to analyze large amounts of data and generate concrete actions to reduce operating and maintenance costs when electricity is produced, minimize losses in its transport, and change behaviors in its final consumption.

However, these advances are only attacking the surface of the problem posed by the new reality of the energy sector. The most radical and disruptive change is yet to come and has to do with the architecture of the market itself and the management of its main product - electricity. With the proliferation of DER, and the need to consider the behavior and preferences of the empowered consumer, a new design is needed to facilitate coordination, traceability, commercial settlements, and the security of power transactions.

IV. Understanding blockchain

DLTs, like blockchain, have the potential to facilitate this new architecture. The blockchain, or the internet of transactions, is the union of several technologies (digital databases, P2P networks, and cryptography) that have existed for decades but have recently been developed in a dizzying way. Basically, this "digital ledger" provides a decentralized and immutable database where transactions are recorded between a network of users, and each and every transaction is viewable by all involved parties. This network can be understood as a web of computers. Each computer must approve a transaction before it is validated and recorded in the database (GIZ, 2018).

Even though the technology was initially associated with the use of cryptocurrencies, its characteristics make it a tool that has the potential to increase the efficiency of any process involving the registration of identity and any transaction associated with that same identity, which can be a good or service. Perhaps, the most important feature of a blockchain is the way in which transactions are validated by network members since it is the members themselves who agree on the rules, or consensus protocols, which act automatically and without the need for an intermediary to decide on the validity of the transactions.

This is why the technology has especially great potential for improving efficiency in all sectors of society that involve the following aspects: i) a need for automation and improvement in process efficiency; ii) a large number of intermediaries that supervise or control these exchanges, which in turn increase final costs for consumers of a good or service; iii) the need for trust throughout the process of exchanging the good or service, so that there is transparency both in traceability and in the quantities or costs of the same; iv) the need for resilience and security of infrastructure in the face of extreme events and external attacks and v) the existence of barriers to access the good or service that prevents the inclusion of all stakeholders in the market (GIZ, 2018). Many of these aspects are reflected throughout the electricity generation, transmission, distribution and marketing chain. As mentioned above, the number of actors and, in general, new devices connected to the electricity grid will significantly increase the number of energy transactions in the decades to come, with the potential consequence of introducing inefficiencies throughout this chain. Considering this aspect alone, it would be worthwhile to research and develop blockchain pilots that demonstrate and quantify the added value of this technology in the power sector.

Challenges of the energy transition

The urgency of a rapid transition towards a cleaner and more sustainable energy system is vital to prevent major impacts of the climate crisis. Renewable energies are one of the most viable alternatives to help address this crisis, diversify the energy mix in our countries, and clean the air in our cities, in addition to the local benefits to economies in terms of the establishment of supply chains and new skilled jobs. Solar and wind generation technologies are already competitive in many regions of the world and have been successfully integrated into the operation of electrical systems. Countries such as Iceland and Paraguay have had a 100% renewable electricity mix for several decades. Others such as Costa Rica, Uruguay, and Norway, have generated more than 98% of their electricity from renewable sources such as hydro, sun and wind in recent years.

Even a developed country like Denmark generated more than 50% of its electricity from vRES in 2017 (IEA, 2019b). They are called variables because they depend on meteorological factors that change geographically and temporally. This feature makes it a bit harder for power system operators whose job is to match electricity production and consumption instantaneously, as this climatic variability introduces additional uncertainty into their already complex scheduling exercise.
This is precisely one of the most relevant discussions at present since it is often said that power systems cannot work exclusively with renewable energies, that is, dependent on meteorological factors, because this would cause instability in the electricity networks. Therefore, the reliability and security of the energy supply would be affected. It is also often said that as the percentage of vRES increases in a power system, it becomes costlier to operate the system, because it then becomes necessary to have a backup of "predictable" or "dispatchable" energy that is generally sourced from fossil fuels sources which would lead to an increase in the final prices of electricity for consumers.

While this trend is confirmed in some cases, especially for high levels of vRES participation in an electricity system, other studies show that existing technology can operate systems with 100% renewable energy without an increase in costs compared to systems based on traditional fossil fuels. In addition, it is important to note that there are already several ways to mitigate the variability of vRES, some of which are increasingly competitive from an economic point of view. The most relevant mechanisms to mitigate the effects of the variability of renewable energies are: i) energy storage, through different chemical or mechanical technologies; ii) forecasting systems, based on meteorological models and artificial intelligence, which can calculate an estimate of the energy production of a variable renewable energy plant so that power system operators can plan the dispatch of this energy in advance; iii) electricity market design, since a better consideration of the temporal production profiles of the electricity from vRES to real-time dispatch, for example through intra-day markets, could make a better use of those resources; (v) demand management, adapting energy consumption where possible to the availability of generation; and (vi) regional integration, with electricity transmission networks that could help smooth out variabilities by creating larger systems with greater complementarity between different geographical and temporal weather regimes of renewables.

Potential short-term applications of blockchain in the power sector

The ultimate objective of any of the mechanisms described above is to increase the flexibility of the power system, in addition to providing complementary services to maintain the reliability and security of networks that may eventually be affected by greater volatility and variability of renewables. With a greater number of distributed generators and devices that can provide these complementary services, the number of transactions will also increase especially at the distribution level. This is where the blockchain can play a fundamental role.
First, the blockchain's decentralization feature can be useful for power system operators, who are accustomed to managing energy flows at a transmission level but seldom intervened at the lower level of the network in an active way. There, a fully automated and secure platform will be needed that can decide autonomously whether grid-connected devices must produce or consume electricity, and whether or not to provide a service of flexibility such as quick curtailing or ramping support, according to the preferences and price signals of the market at that level, but without the need of a full centrally managed system like current wholesale markets. In a power system based on blockchain each participant will have its own digital identity and all interactions with the rest of the "digital community" will be recorded transparently according to the rules of the platform (EWF, 2018).

This record of digital interactions can also be very useful in providing national or regional governments with another very relevant aspect of the energy transition, such as monitoring and tracking carbon markets and emission reduction credits or renewable energy certificates. There are already more than 51 carbon price initiatives implemented worldwide, including carbon tax programs in 26 countries that aim to give market signals to encourage technological innovation and decarbonize their economy (WB, 2018). This registration and control of certificates are currently mostly handled by centrally managed databases and servers presenting great inefficiencies that will tend to increase as more and more companies and consumers want to certify the origin of the electricity they consume. Blockchain technology can help digitize the identities of credit sellers and buyers and register their acquisition and ownership changes in a transparent manner with low transaction costs.
Finally, another possible blockchain application in the short term is the financing of distributed energy resources. Small-scale renewable energy projects are generally very complex to finance due to their high transaction costs, and the low credit capacity of the users involved. These costs can be reduced if a platform is available that, in addition to reliably recording the

ownership of credit subjects, can digitally agree on the rules of governance, ownership, and distribution of project revenues. Another option is the monetization of future electricity flows from projects, thus giving the possibility of participation to a greater number of investors. This aspect may be much more relevant in developing countries where the availability of capital for such small-scale projects is scarce.

Blockchain use cases in the power sector in Latin America

The majority of blockchain projects in the power sector have been implemented in Europe, the United States, and Australia. However, there are already some initiatives also in Latin America aimed at demonstrating the added value of this technology by making energy management more efficient and encouraging greater participation of renewable energies. Although Latin America is a region with an electricity mix with a high percentage of renewable energy, especially hydropower, the share of vRES is still limited and was around 5% in 2018. According to a study by the IDB, this means that only 0.01% of the gross potential available of solar energy and 0.2% of wind energy in the region has been tapped so far. The same study states that the share of vRES will increase at least 4 times by 2030 in a conservative scenario due to the competitiveness of vRES technologies against traditional fossil fuels (IDB, 2017).

Two important initiatives are taking place in Chile at the transmission and distribution level. The first aims at certifying the electricity that comes from wind plants connected to the transmission grid since corporate clients who purchase this energy are interested in demonstrating, in a secure and transparent manner, the "green" origin of the electricity they consume (Acciona, 2018). This growing trend in the corporate world responds to sustainability targets and to increasing pressures from environmental groups, society, and shareholders themselves.

The second initiative is a solar energy traceability pilot for a total capacity of about five MW, distributed in more than 130 photovoltaic systems in buildings participating in the "Public Solar Roofs Program" in seven Chilean cities. In this case, the objective of the pilot project is to give transparency to the monitoring of the reduction of greenhouse gas (GHG) emissions achieved through these systems and to be able to establish, in the long term, a national registry for the carbon market (Phineal, 2019). In addition, the Chilean government has also developed an open data initiative using certification via blockchain technology, which aims to encourage citizen participation in regulatory processes and increase the sector's trust and transparency to all stakeholders (CNE, 2019).

The Inter-American Development Bank through IDB Lab is also implementing in the framework of the regional program LACChain an interoperable and multisectoral platform with blockchain technology that allows the development of applications with inclusion criteria. The program also aims to create a network of national blockchain ecosystems integrating public and private actors, in addition to establishing standards and regulations that adapt to the needs and legal frameworks of each country (Pardo, 2019). According to the characteristics and needs of the power sector in Latin

America, the potential applications in the energy sector that could be developed in this platform are oriented towards access to sustainable energy, carbon markets, and regional integration.

In the first case, applications could be created that account for GHG emission reductions in isolated systems or mini-grids with vRES. Moreover, financing mechanisms could be created that monetize both the electricity produced and the emission reduction certificates so that capital can be attracted for these projects. This is particularly relevant given their complexity, these projects are typically not attractive to commercial banks or traditional investors and depend on high subsidies from the public sector. Blockchain can provide a safe, decentralized, and transparent platform for these types of initiatives that have already been implemented in other regions, for instance in Puerto Rico. Here, after Hurricane Maria the issuance of municipal solar bonds is being tested to finance solar systems in 700 schools that can also serve as emergency shelters in the event of extreme weather events (Yale, 2019).

Another potential application relates to regional transactions of excess renewable power between countries as commercial settlements between sellers and buyers tend to be a very complex process requiring several intermediaries, in addition to the different currencies that are handled between different countries. In a regional context, the use of DLT platforms for electricity payment systems in charging stations for electric cars on international routes, similar to the concept of roaming for cellular networks, is being investigated in other regions outside of Latin America. This is the case of the European Union (EU) funded NeMo platform that aims to create an open and distributed pan-European backbone and ecosystem for seamless interoperability of electric mobility services (NeMo, 2019).

V. Conclusion

While rapid progress has been made in other sectors, such as virtual payments in the fintech industry, the added value of blockchain in the energy sector is beginning to be discovered worldwide, as the first results of the pilots are analyzed, and the efficiency of the consensus protocols and the scalability of the platforms continue to improve. Considering the urgent decarbonization needs of society, and at the same time the slow pace of the energy transitions in the history of society, it is a fortunate coincidence that blockchain has the potential to empower each and every user of the electricity grid to participate more actively in deciding how to produce and manage the electricity we consume every day. In this way, digitization will be the tool, and not the ultimate goal, to achieve a rapid energy transition to a 100% renewable energy world.

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3. Blockchain and renewable energy: An overview of the opportunities for Mexico

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I. Abstract

Blockchain technology and other technologies such as IoT and Big Data are disrupting some of the most technology lagged sectors. Electricity has been produced in the same way for the past 120 years: in a centralized way and mostly using non-renewable sources. The exponential price reduction of distributed generation systems, especially PV, is turning the decentralization of energy into a reality. New business models in the electricity sector involving blockchain have appeared in most parts of the developed world. Mexico is changing its finance and energy legislation in order to be more financial inclusive and take advantage of locally produced energy. There is still a lot to do to consolidate this nascent merge between sectors, but the roadmap is in place.

II. Key words

Renewable energy, blockchain, prosumer, smart contracts, crowdfunding

III. Blockchain: a core element in the electricity markets of the future

Electricity systems are being challenged by the introduction of high volumes of renewable energy generation from decentralized sources that demand for new tools to maintain safe operation and stability. Also, the electricity sector is on the edge of digitalization with the deployment of sensors and smart devices at the premises of every consumer in numerous countries. In 2017 Mexico produced 329 TWh, 21% came from renewable energy sources mainly from hydro, geothermal, wind and solar (Prodesen, 2018). Mexico is predicted to have around five GW of distributed generation by 2023, with more than 600,000 prosumers (CRE, 2018). Grid flexibility is needed in order to absorb renewable energy sources. DSR and energy storage services will play an important role in the integration of such new energy sources. There is a growing interest in blockchain technologies in the electricity sector because blockchain enables distributed transactions with transparency and immutability. Therefore, it is an ideal technology to face the challenges of decentralized generation systems.

Blockchain technology is the union of different technologies such as cryptography, P2P networks, and data ledgers. The most famous use of blockchain is Bitcoin. Bitcoin was born in 2008 (Nakamoto, 2008) with other cryptocurrencies appearing thereafter with different applications. According to a Gartner report (Gartner, 2018), the peak of inflated expectations already passed for blockchain technologies. The report stakes that all emerging technologies transit between different stages in the hype cycle. From innovation trigger and peak of inflated expectations where hype is at its maximum, to the valley of disappointment and at last the plateau of productivity. Concrete developments will appear only now that hype has passed. One of the clear opportunities of blockchain technology is the energy sector where all major utilities are exploring use cases (EWF, 2019).
For the past 120 years electricity generation and trading have been unidirectional. Electricity is usually transmitted from large-scale generators to consumers with a limited number of decision makers along the supply chain (Accenture, 2018). A decentralized energy system is a relatively new approach because it seeks to put power sources closer to the end user, thereby reducing transmission and distribution costs. Blockchain technology could give decentralized energy systems a new way to organize themselves and could become a central part in electricity markets of the future. (Burger et.al., 2016).

Different research institutes and startups, especially in the EU, believe blockchain technology could enable the 3D's: decentralization, decarbonization and digitalization of the electricity sector, while empowering prosumers (Dobbenni et.al., 2017). The reality is that applications like Bitcoin with a complete decentralization and an expensive infrastructure to maintain are not the best for the electricity ecosystem (EPRI, 2018). Different consensus protocols are proposed. All of them have advantages and challenges ahead. Some of them tackle issues like security and energy consumption in different ways. In

this article different consensus protocols, international experiences, regulation of the financial and energy sector in Mexico will be presented and discussed as well as the opportunities that digitalization brings to power markets.

Fintech in Mexico

In 2017, Mexico approved the so called 'Fintech Law' (Hogan, 2017), recognizing virtual assets such as Bitcoin and Ethereum (Ethereum, 2015) and regulating crowdfunding as an alternative financial method as well as sandboxes to allow innovative business models. In September 2018, the National Banking and Securities Commission (CNBV) approved secondary legislation of the fintech law (CNBV, 2018), capping crowdfunding to a maximum of 2.3 million USD per project. In March 2019, Mexico's Central Bank (Banxico) released a possible additional legislation, mentioning cryptocurrencies will only be allowed for "internal operations in a company" (Helms, 2019). In 2019, Banxico started the use of its mobile payment platform called Cobro Digital (CoDi) which boosts financial inclusion, allowing money transfers through QR codes (Cuesta, 2019).

Mexico's Electricity Market

Mexico had a mayor energy reform in 2014, formally opening the market to foreign investment and aiming for higher shares of renewables by setting a target of 35% clean energy by 2024 (SENER, 2019) and 50% by 2050. The reform included market mechanism such as CEC and classified big and small consumers.

According to Mexican legislation, a small consumer is one with an installed load below one MW (KPMG, 2016). Those consumers have limited options to reduce their electricity bills. They can either aggregate loads in order to reach one MW and buy electricity through a qualified supplier in the wholesale market or they can install distributed generation technologies, such as PV, to take advantage of net metering and net billing contracts with the Federal Electricity Commission (CFE), the state utility (Heidell, 2017).

Distributed generation systems in Mexico surpassed the 90,000 mark with more than 692 MW in place (CRE, 2018). A generation system is considered to be distributed when its capacity is below 0.5 MW (Villavicencio, 2019). A recent study showed that Mexico's distribution grid can host 28,000 MW of distributed generation. This means that the actual potential for new distributed generation systems is only at its infancy.

IV. Blockchain opportunities for Mexico's power market

Blockchain basics

Blockchains run on digital networks. Data transmission in such networks is equivalent to copying data from one place to another, e.g. in the cryptocurrency domain this is equivalent to copying digital coins from one user's electronic wallet to another's. The principal challenge resides in the fact that the system needs to ensure that coins are only spent once, avoiding double-spending. A traditional solution is to use a central point of authority, such as a central bank, who acts as the trusted intermediary between transacting parties. Their job is to store and guarantee the validity of the ledger and keep the records up to date. If multiple parties need to write in the ledger at the same time, a central authority also implements concurrence control and consolidates changes in the ledger. In several occasions, central management may not be feasible or desirable, as it introduces intermediary costs and requires network users to trust a third party to operate the system (Grewal-Carr, 2016). Centralized systems also have significant disadvantages due to a single point of failure, which renders them more vulnerable to both technical failures and malicious attacks (Mattila, 2016). The primary purpose of blockchain technologies is to remove the need for such intermediaries and replace them with a distributed network of digital users who work in partnership to verify transactions and ensure the integrity of the ledger.

If central management is removed, the challenge resides in finding an efficient way to consolidate and synchronize multiple copies of the ledger. The exact process of validation and ledger consolidation varies for different types of blockchains. These validation mechanisms are known as "distributed consensus algorithms" (Baliga, 2017).

Blockchains can be public or private, the only difference is related to who is allowed to participate in the network (Zibin, 2017).

Table 1: Differences between public and private blockchains

Concept	Public Blockchain	Private Blockchain
Registration	Anonymous and free access	Invitation only Know Your Customer (KYC) control
Blockchain	Descentralised data storage and verification performed by P2P networks	Centralised/descentralised data with one or more operators
Manipulation	No ex post revisions are possible	Ex post revisions are possible
Costs	Higher operating costos	Lower operating costs with operator fees
Scope	Resilient with but low scalability	Participation controlled but very high scalability

Source: Author contribution

There are different protocols of consensus in blockchain technology. These are rules that each network uses to validate information. The methodology to reach consensus is intrinsically related to transaction speed, security, transparency and scalability.

With PoW, the most famous consensus algorithm, used by Bitcoin, miners compete with each other to add a new block to the existing blockchain by solving a puzzle. Miners have no way to predict or influence the outcome, so the only feasible action is that of trial and error. This brute forcing procedure requires computational effort and hence electricity. When the puzzle is solved, the block is returned to the Bitcoin network and is accepted by other nodes if all transactions are valid and unspent, and the successful miner takes a financial reward (Kroll, 2017). By starting work on the consecutive block other miners accept the newly generated block. Crucially, all succeeding blocks contain puzzles solved from all preceding blocks. As the generation of new puzzles is random and performed in parallel by many miners, multiple chains may appear. In this occasion, the network stores all resulting chains. Network members eventually abandon all other chains but the longest, which is assumed to have been produced by a network majority of computational power and therefore represent the most valid state of the ledger. As a result, malicious attackers are constantly outpaced by the honest part of the network, unless they can control more than 51% of the computational power in the network. In the case of a 51% attack, malicious nodes could potentially rewrite the entire history of transactions.

One of the disadvantages of PoW is the computational power needed to perform the tasks in order to validate the transactions, something that requires vast amounts of electricity. Sources report that Bitcoin could consume as much electricity as Denmark by 2020 (Deetman, 2016). On a more positive note, a recent study made by Coinshares concluded that Bitcoin procured 77% of its energy consumption from renewable sources (Bendiksen, 2018).

PoS is yet another way to validate a transaction. It aims to achieve consensus by replacing the brute force of computational power and energy consumption with a random selection process depending on the wealth of each of the participants or node owners (Blinder, 2018). This makes the blockchain reach consensus a lot faster and less energy intense. The rewards are different than new coins. Instead, they only take transaction fees.

Ethereum, one of the most famous blockchain platforms, is contemplating the move from PoW to PoS (Kim, 2019). This means changing the software protocol that supports the blockchain by the participants involved. This update is called a hard fork and is meant for reducing the number of rewards given, therefore reducing inflation pressure in the cryptocurrency. Given the energy demand of a PoW approach, a number of developers are showing preference for other consensus algorithms such as PoAu.

The block generation in PoAu requires granting special permission to one or more members to make changes in a blockchain. For example, one member holding a special key may be responsible for generating all the blocks. Essentially, PoAu can be seen as a modified PoS algorithm, where a validators' stake is their own identity.

Network members put their trust into authorized nodes and a block is accepted if the majority of authorized nodes sign the block. Any new validator can be added to the system via voting (Andoni et.al., 2018). Although the method represents a more centralized approach, most appropriate for governing or regulatory bodies, it is currently also proving popular with utilities in the energy sector. An example is the Energy Web blockchain that will run on a proof of authority algorithm named Aura (Bentke, 2018).

Blockchain meets energy

Blockchain technologies could also be applied to a variety of use cases related to the operation and business processes of energy companies. Potential applications for the Mexican market are (McKinsey, 2018):

- Automated billing for distributed generators with smart contracts,
- Micropayments or pay-as-you-go as well as pre-paid energy consumption,
- Tailor made solutions with smart contracts and artificial intelligence (AI) depending on energy profile,
- Carbon certificates, green certificate or CEC trading,
- P2P platforms or market places.

International best practices

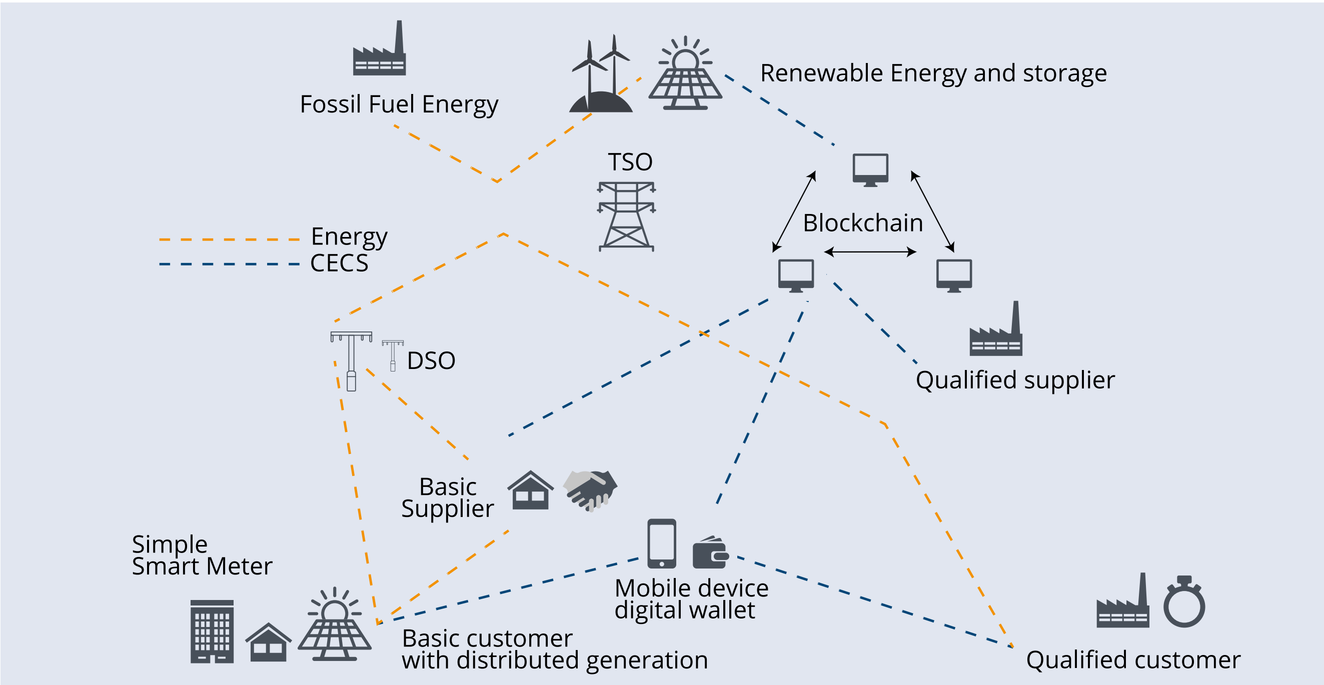
Several developers are working on the use of blockchain technologies for renewable or carbon certificates, their automatic issuance and trading.

One of the first solar energy certificates on blockchain was Solar Power Certificates developed by Linq platform in 2016 (Linq, 2015). Solar Coin is another example: for every MWh of solar energy fed into the grid producers are awarded one SolarCoin, which can be either stored in a SolarCoin wallet or converted to bitcoins. SolarCoin (Deign, 2019) partnered with SMA, a German inverter manufacturer, to tap several GW of small and medium sized generators around the world. Another relevant example is NRGcoin (NRGcoin, 2018) which was born as an academic project and is now continued by Enervalis. The NRGcoin mechanism replaces traditional high-risk renewable support policies with a novel blockchain-based smart contract, which better rewards green energy.

Prosumer-centered market places

While the centralized energy market structure has a limited number of decision makers, decentralized structures may involve a large number of actors, among which specific market and business models need to be coordinated, requiring specialized methods. One example of decentralized structures are renewable energy communities, especially in Europe and the US. In those communities' citizens take collective action in a renewable energy project at different stages with different roles (Rescoop, 2018). These decentralized structures are relatively new in Mexico. In such systems, blockchain in combination with emerging fields such as IoT and smart meters digital wallets and smart phones (Pwc, 2016) can trace energy from generation to consumption, from business to business using the distribution system. Also, blockchain enabled platforms can facilitate the emergence of a market for CEC produced by distributed generation.

Figure 1: Proposed structure to sell CECs from distributed energy to an energy supplier



Source: PwC, 2016

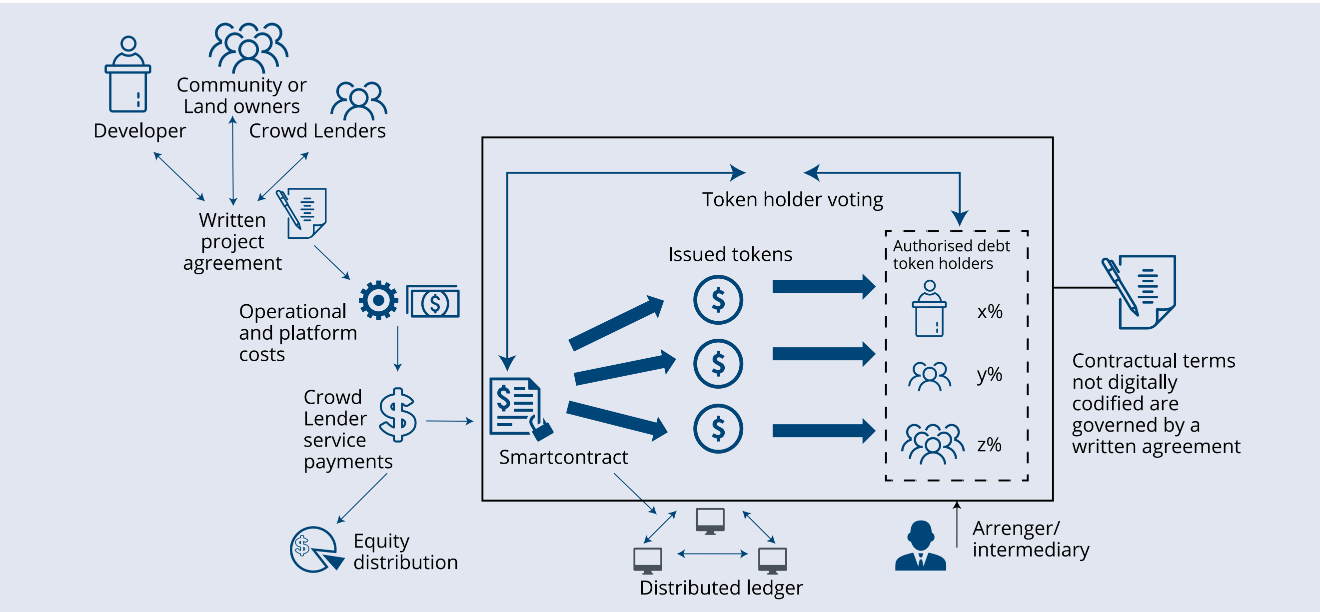
Smart contracts and crowdfunding platforms to fund renewable energy assets

"Smart contracts" are basically a code on top of a blockchain that contains a set of rules agreed by the parties (BlockchainHub, 2016). The contract negotiation is embedded in the code. This means, with smart contracts you can program money transfer "if" something happens. This has the potential to reduce administrative costs between institutions or people.

Smart contracts turn legal obligations into a code, with automated processes, thereby self-verifying and guarantying security in every step of the process. Smart contracts can help crowdfunding platforms reduce operational fees and make project finance structures less expensive, ideal for small PV projects (Cerezo, 2017). Crowdfunding started with Kickstarter ten years ago in New York (Kickstarter, 2009). This Brooklyn company and other startups helped entrepreneurs finance their projects through internet-based platforms. They have had some setbacks in the sector due to fraud and major delays in successful projects (Carpenter, 2017). These first platforms focused on products and services and less in making business. There are several crowdfund and P2P lending companies already in operation in the Mexican market such as Kubo Financiero (Kubo Financiero, 2019). Some of them were established well before the 'Fintech Law'.

On the energy side, Mexico has excellent solar irradiation and has instruments such as net billing schemes to help the adoption of PV systems. As mentioned earlier, systems below 0.5 MW are considered distributed generation and benefit from lighter regulatory and permitting processes. Net billing is the most used contract when PV generation is installed. This is because it reduces the other components in the tariff which are payed in $/kWh net consumed. International experience for crowdfunding in solar is mainly limited to Europe, where "Wesharesolar" is a clear example of how banks, crowdfunding, and even other participants like governments and land lords can benefit (UNFCCC, n.d.). Figure 2 is an example of how a smart contract can help build new distributed generation in Mexico by involving local communities. Smart contracts are a transparent and safe way to involve the community in solar projects in the near future.

Figure 2: PPA tokenized with communities



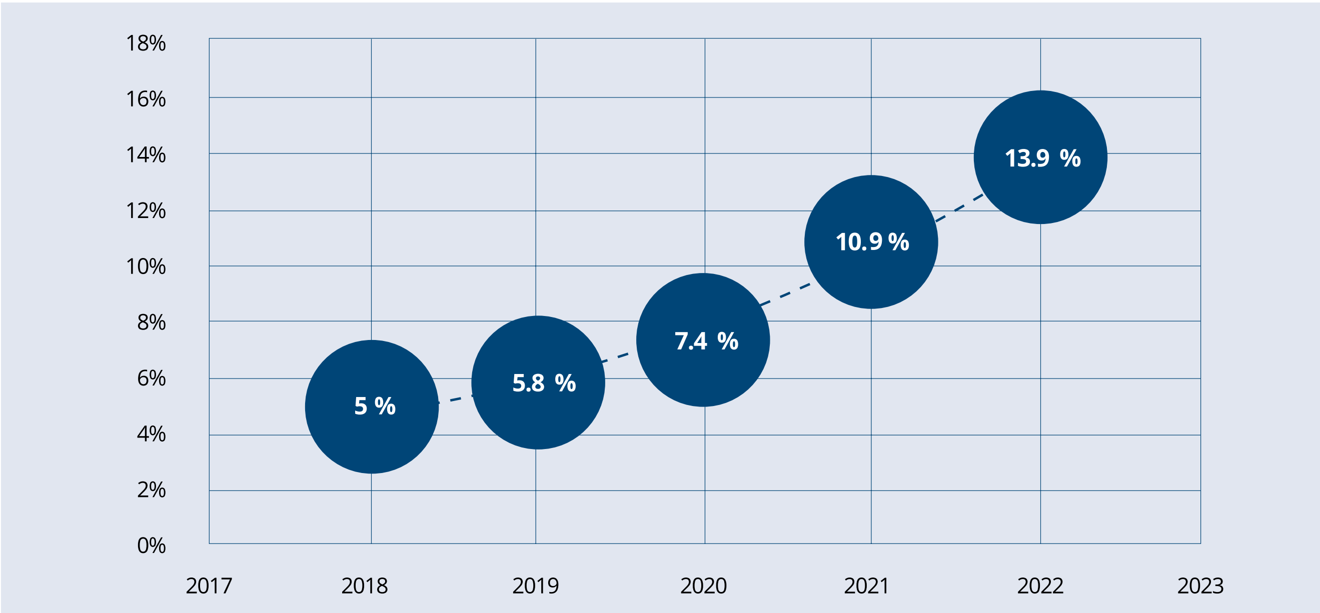
Source: Adapted from Moseley, 2019

The different stakeholders in a distributed energy project are represented in Figure 2, where the developer can be a legal entity with resources and know-how to build distributed generation with or without equity involved. The community can use neighborhood parks or the rooftops of public spaces. Community members can have voting rights depending on their involvement and leasing fees. The crowd lender can be anyone investing money to support the project. The operational costs including the platform costs should come from the key stakeholders mentioned above, including due diligence and permits. A project agreement should include every part of social and economic analysis. A smart contract can be put in place by a third-party arranger, issuing tokens as right votes of the debt raised by crowd lenders or any other financial entity. Based on the votes coming from different actors, the project can be sold or refinanced during the lifecycle of the project.

Mexican CECs as a stable coin

The Mexican state through the Ministry of Energy (SENER) puts a target on the percentage of energy that has to come from renewable energy, in the form of CECs (Energía a Debate, 2019).

Figure 3: % of CEC obligation in Mexico



Source: Valle, 2017

CECs are a useful tool to identify the energy produced from clean energy sources. The Energy Regulatory Commission (CRE) is responsible for issuing CECs (LIE 2014). Qualified and basic suppliers and qualified users are the buyers of CECs. In Mexico, the 674 MW of distributed generation do not request any CEC, because the costs associated with the certification process and the installation of a smart meter are too high and do not justify the investment. A typical home with five kW installed PV capacity would need to go through a manual process performed by a certified third party, costing on average about 3,000 USD:

1. Energy Meter complying with the regulator	**$**	**1,500 USD**
2. Third party certification for a 5 KW	**$**	**500 USD**
3. CEC Platform yearly registry for generators	**$**	**1,000 USD**

Source: Author contribution

Simple smart meters integrated with blockchain solutions could link the CECs produced by distributed generation to a cryptocurrency or a "stable coin". A stable coin is a cryptocurrency that has a pegged value and does not have extreme volatility (Bitsgap, 2019). In this case a cryptocurrency would be pegged to the value of the CECs and could be sold in a secondary market to different basic and qualified suppliers as well as qualified users around the country at a competitive price. Each generation system should be linked to a smartphone and a wallet to store and trade CEC's. CRE and other regulators could trace each CEC because each transaction will be in the blockchain.
Any CEC has a unique digital footprint with the following information (CRE 2018):

P	P	P	P	C	T	T	M	M	A	A	X	X	X	X	X	X

Where:

PPPP:	Represents the plant generating the CEC's.
C:	This character can be "G" if its above 1 MW of clean energy or "S" if it is below.
TT:	The renewable technology used to produce the energy.
MM:	Month each CEC was produced.
AA:	Year each CEC was produced.
XXXXXX:	Consecutive number of CECs corresponding to each generator.

With the digital footprint, the regulator can access and verify the name, location and technology used for issuing the certificates.

The CECs prices depend on the market. Last Long-Term Clean Energy Auction was held in 2017 with the lowest price at 8.6 USD/MWh, and the highest at 22.4 USD/MWh (Zarate, 2017).

Not only could the use of a cryptocurrency help keeping track of the number of CEC, but its origin too. CRE has already started the process to evaluate the technology while identifying several other interesting uses (Madrigal, 2018).

V. Conclusion

The use of blockchain technologies allows for the reduction of costs, increase of transparency and immutability to the electricity sector's stakeholders. With an appropriate blockchain architecture, final users, prosumers, markets, regulators and distributed system operators can benefit in the medium and long term from this technology. Today, distributed generation and small renewable producers are a minority in terms of installed capacity, but it is growing fast. Blockchains are meant to transform the energy economy by truly democratizing the energy production. The intersection of energy markets, digital technologies and appropriate legal frameworks can accelerate the energy transition to be more inclusive with the most vulnerable. Deep knowledge about these three fields is a limited resource. Regulators, policy makers and private sector must understand the underlying opportunities of blockchain technologies to accelerate the implementation of projects and the creation of new business models in this nascent field.

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4. Sello Sol & Blockchain GTIME – Electricity traceability system using blockchain

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Phineal

Diego Hermosilla
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I. Abstract

This article describes the development of an electricity traceability system with blockchain technology. It refers to the programming of a smart contract housed in a local network, which incorporates a loss allocation methodology to complete the electricity supply chain between a photovoltaic plant and a final customer, contemplating production (generation), consumption and transport losses; this addition is fundamental to secure the validation of the project from a physical point of view. In accordance with the current regulatory framework in Chile, it is decided to assign the aforementioned losses are assigned to the final customers, using the pro-rate or postal stamping method, which has been incorporated into the coding of a decentralized app (dApp) developed by the company Phineal to achieve a self-executing energy traceability register. The dApp relies on the use of a smart contract deployed in Ethereum, using the Oraclize tool to import the injection/withdrawal data published in the Sello Sol certification website (based on the GTIME blockchain protocol) and the generation/demand data extracted from the "Energía Abierta" website of the National Energy Commission (CNE). With this dApp, it is possible to compile, in ranges of 20 minutes, an instantaneous supply chain that has two levels of validation in its data of origin, to use in certificates of production, supply and supply chain of a smarter "green electricity". This is possible due to the work with energy data gathered by the permissioned energy meters from the GTIME blockchain network, and thanks to the public consensus of the Ethereum network.

II. Key words

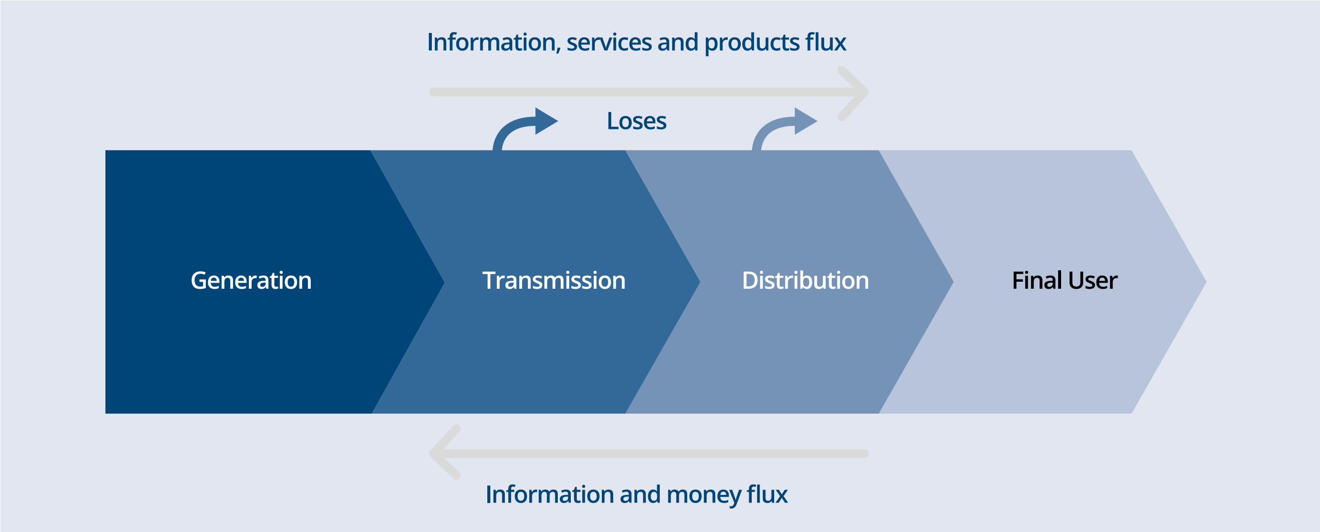
Energy traceability, federated blockchain, smart contract, Ethereum

III. The traceability of a product

According to an article published by the Electricity and Electronics Industry Association (AIE) of Chile (Pinto, 2018), the traceability of a product is understood as a set of actions and methods that enables recording and identifying each activity through which it passes, from its genesis to the final customer. Proper follow-up is obtained thanks to the use of specific tools to find the history, location and trajectory of the product throughout its supply chain.

Electricity understood as a product can also be tracked at all stages of its supply: generation, transmission and distribution. For this purpose, telemetry instruments, registration and data storage systems are used, which are particularly useful both for invoicing and for continuity in the payment chain of the electrical power system.

Figure 1: Electricity supply chain. The traditional system centralizes production and consumption



Source: Phineal, 2018

With the traditional supply chain illustrated in Figure 1, where the production and delivery of electricity are articulated to supply final customers, it is made clear that the traceability of electricity is only a mechanism for verifying the quantities agreed in one-way contracts in terms of power, energy and money. In addition, since any current flow in the electrical power system is subject to the law of energy conservation, it is natural to incorporate the losses due to the Joule effect incurred during transport. These, which due to their non-linear nature represent a challenge in the tracking and assessment of the agent or agents that produce them, are assigned by various types of collection factors, such as the determination of the average node price of the national and zonal transmission system established in 2017 by the CNE.

However, in accordance with Orecchini et. al. (2015), in a scenario where consumer preferences are increasingly oriented towards products and services with a low carbon footprint, such as renewable energy sources, and those associated with the control of electrical variables via IoT, under which consumers become "prosumers", the energy sector has been forced to rethink the concept of traceability, since this can represent an important differentiating element at a commercial level, strengthening the value chain of "green electricity" while improving its supply chain. Thus, it would no longer be enough to just know the nature of the generation sector or the demand, but as the prosumers take a more active role in the market, the purchase/sale prices and the environmental impact of the technology, the positive externalities of the P2P exchange and even the political character of the generation will get a special relevance. The latter makes sense because, under some circumstances, a decentralized energy model can work in harmony with the concept of collaborative economics (Cañigueral, 2015).

In this sense, the electricity production traceability through the GTIME blockchain protocol represents an opportunity to materialize a collaborative economy, since it would facilitate the monitoring and secure storage of all information related to the energy supply chain.

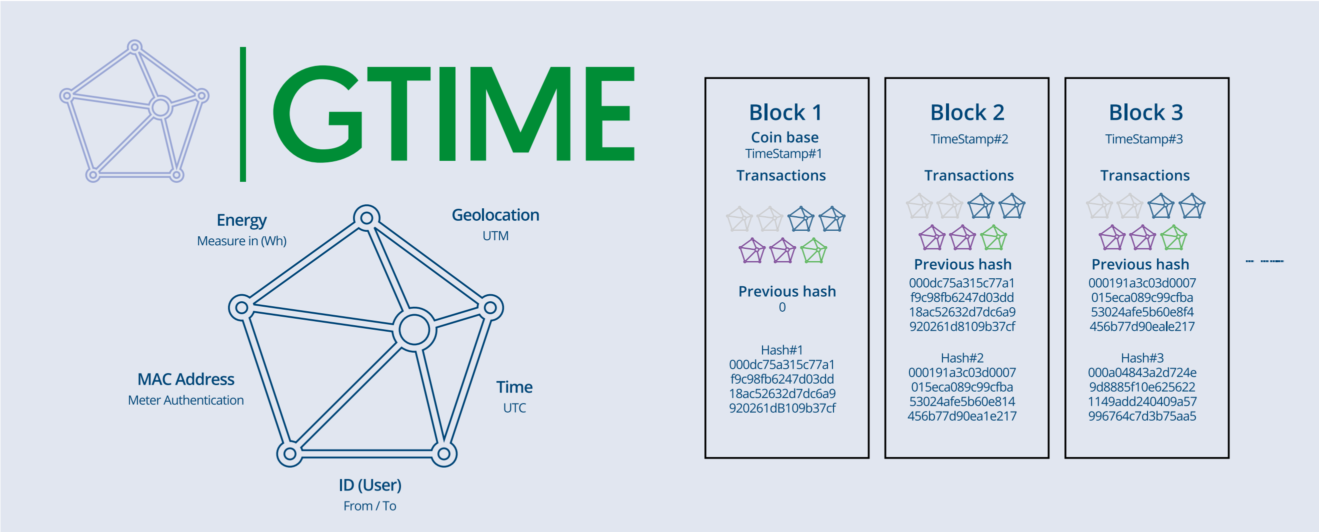
IV. Energy traceability with blockchain

GTIME blockchain

The electricity traceability system developed by Phineal is based on a chain of federated blocks called GTIME blockchain, which is an immutable record of electricity transactions, agreed and maintained by a distributed network of independent computers.

Each registered energy transfer has a time stamp, geolocation and authentication of the measuring devices, serving as proof of origin of injections and/or withdrawals at a specific point of the power system through an online consultation of the history of the transactions made (Phineal, 2018). By this, it is possible to answer all the questions about the energy source, such as: where is the energy being generated/consumed? when was the energy registered? who injects/removes the energy? and, how much energy is at stake?

Figure 2: Blockchain GTIME. Icon symbology and concatenation schemes



Source: Phineal, 2018

To measure empirically the variables involved, the initiative has two devices developed especially for these purposes: phiNet and phiNergy, which are installed directly at the generation plants and/or consumption centers suited to record the electricity produced or demanded (Phineal, 2018).

These devices are designed to gather and broadcast within 15 minutes, an information package containing the georeferenced location of the meter, the exact time in which the energy has been registered, the user ID, the MAC Address of the device and the amount of electricity in [Wh] that has been measured (Phineal, 2018). This information vector is called "GTIME", an acronym in response to the initials of the five variables mentioned above and is symbolized by the pentagon illustrated in Figure 2.

Within 5 minutes, the devices establish a machine to machine (M2M) communication over the internet with Phineal's blockchain platform to store the obtained data. Therefore, in a 20-minute interval, the total set of phiNet and phiNergy devices captures, registers, orders and packs the energy information of the associated electricity network and then sends it to the GTIME blockchain, where the time stamp is "stamped" on the group of vectors, then a block is created and linked to the chain, as shown in Figure 2.

The block is then subjected to a mining process for the allocation of the hash, which allows the incoming transactions to be ratified and incorporated into the blockchain. With this, a global consensus of the validating devices is established, making possible the energy traceability by the online request of the network's electrical transfers history.

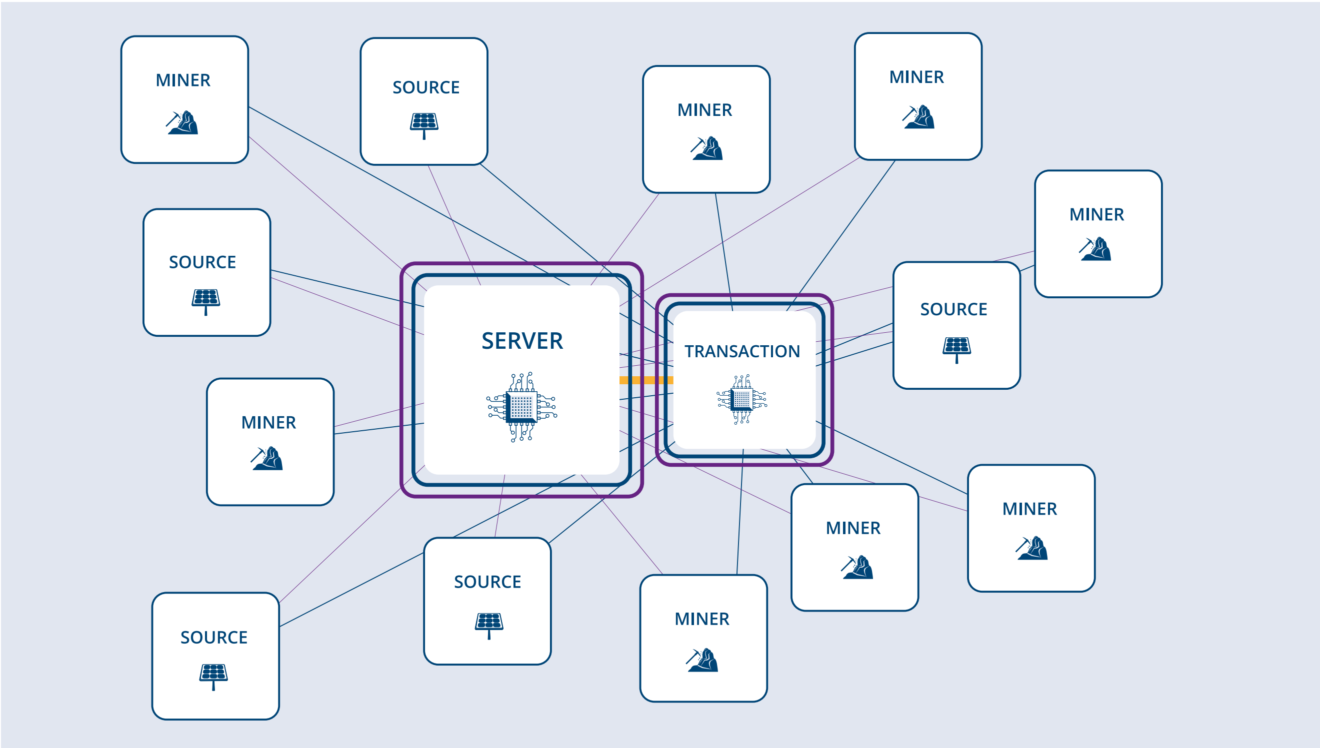
Taxonomy and technological prototype of the traceability system

As for its taxonomy, the GTIME blockchain is a dedicated blockchain network (hybrid or federated). This is because it is Phineal who is responsible for vetting each of the participating nodes through a license that gives access to the network. In this sense, there are no economic incentives for sealing the blocks, avoiding the excessive increment of the mining difficulty and, with it, reducing the computational costs implied in the confirmation and maintenance of the blockchain. This idea implies that the assemblage of the external validating nodes to Phineal's own miners cannot have a profit incentive, such as for example autonomous governmental entities, organizations or any other institution that would wish to monitor energy generation and consumption.

The last feature to categorize the GTIME blockchain as a dedicated blockchain is that the transaction information is uploaded to a web platform, from where it is possible to publicly consult the amounts of energy transferred, as well as the agents involved in that movement. However, access to a copy of the chain is only available for those nodes belonging to the network.

Due to the nature of the data with which one works in an electricity system (i.e. physical magnitudes such as currents, voltages, power flows, etc.) and given that the natural laws that justify the amount of these variables are based on measurement and observation (such as the law of energy conservation), it is inferred that in a blockchain network of this kind there is no room for speculation of the quantities traded. This confers that, at least at a physical level, the hybrid category of the GTIME blockchain should not derive in conflicts of information transparency; justifying the centralized selection of nodes only by the respective technical quality of the measurements, the efficiency of the data collection and the calculation of hashes. At a conceptual level, the schematic distribution of the nodes in the first version of the Blockchain GTIME network is as shown below in Figure 3.

Figure 3: Schematic composition of the GTIME blockchain in its first stage



Source: Phineal, 2018

As can be seen in the previous image, in this first version of the GTIME blockchain, four fundamental elements with clearly defined roles are established (Phineal, 2018):

a. Nodes:

The nodes that form the distributed network can be of two types: meters and validators. Within this last group, there is room for the existence of independent computers external to the company's property, since it is the validating nodes that support decentralizing the transfers of the electrical system.

b. Generation/demand metering nodes:

- phiNergy meter: it consists of a "Raspberry Pi Zero W" PCB, an electronic board that enables the connection of sensors and a non-invasive amperometric clamp. Currently, these meters are designed to measure low voltage energy, so its use is aimed at a domestic, retail and small industrial scale.
- Meter with phiNet link: In the case of large power generators, a phiNet monitoring station (phiNet 10/11 models) is used to link the data between the inverters or billing meters in the power plant and the solar radiation, temperature, georeferencing and time parameters measured simultaneously by the monitoring station, which will be responsible for uploading the information to the phiNet database. The idea is to use the phiNet platform to compare the energy production of the plant with the monitoring stations forecast ("solar benchmarking"), or to save a backup of production data from the plants.

c. Validating nodes:

Physical miners are minicomputers "Raspberry Pi 3 Model B" that decentralize the validation of transactions and allocate the hash of the incoming blocks to add them to the chain. As mentioned above, data mining under the GTIME protocol is based on the PoW consensus protocol and the cryptographic function SHA-256. However, unlike Bitcoin, the hybrid nature of blockchain GTIME means that there is no room for forks; therefore, no computational effort should be added to discover which is the "honest" version of the chain, as there is a single version.

d. Server and transaction

The server, like any other server, corresponds to the computer unit in charge of storing and supplying the data required by all the nodes of the distributed network. The information that can be transferred is diverse, but for this application, it is basically limited to the traffic of GTIME vectors, to the emission/reception of new blocks and to the storage of the blockchain's memory. The transaction unit, on the other hand, is a task that exists in the server and is in charge of receiving the data gathered by the measuring nodes, grouping the GTIME vectors in an open block, notifying the miners that there is a new sealing order and, finally, sending the open block to the selected validator.

That said, if Figure 3 is reconsidered, it will be possible to notice that in this first version of the GTIME blockchain the distributed network uses a single server and the nodes are not communicated directly or P2P. Instead, each node sends a status update to the server to show the availability of the meter or validator (online or offline), and with it, makes a request for the status of the new blocks in order for the nodes to acquire an updated copy of the blockchain. Once the availability of each meter is confirmed, the stored GTIME vectors are delivered to the transaction unit, a portion of the server which is ready for the nodes to consult the pending transactions and mining, to form a new block. PhiNergys and phiNet-linked meters "ask" the transaction server if the last available block is still open to store the data there, while miners "ask" the transaction server if the last available block is ready to be confirmed.

If a block is ready to be confirmed, the metering nodes stop uploading information and dedicate themselves solely to capturing data, while the validating nodes "compete" to subject the last block found in the transaction to a mining process. When a new hash is found by one of the miners, it returns the sealed block to the server, so that it can incorporate it into the chain and save and update the blockchain version. Finally, through a "request", all the connected nodes will obtain a new copy of the chain of blocks, finishing the cycle of a process whose current duration is approximately 20 minutes.

The GTIME blockchain code has been designed so more servers can be added in later versions or, ideally, a P2P architecture can be adopted (Phineal, 2018). This point is relevant since, at the moment, all the nodes of the distributed network can "check" that their "ledger" is updated through a "request"; however, the only element that stores the information contained in the blockchain is the server. Therefore, it must be understood that the GTIME blockchain intends to migrate towards a totally decentralized architecture in regards of data storage.

Case study: Application of a loss allocation methodology in a reduced model of the National Electric System (SEN) of Chile

In order to study the energy interaction between two locations connected to the same power system, it has been determined to conduct a study of the supply chain between the Salvador PV plant connected to the Diego de Almagro busbar (in Atacama, Chile) and an end consumer in Providencia, connected through the distribution company to the Cerro Navia busbar (in Santiago, Chile). The analysis focused on an electrical system with permanent load flow, where the physical magnitudes are subject to a specific time instant.

To this purpose, work has been done to select just a segment of the official transmission network circuit of the SEN published by the system operator (National Electric Coordinator, 2018), which includes both transaction agents and the most important lines and bars connected to them.

From an electricity point of view, it is good to emphasize that, given that the only subject of interest are the instantaneous amounts of the active powers that transit through that portion of the SEN, the selected portion of the system has been made under the condition that all the injected and consumed powers must obey the real operating criteria of the SEN, that is to say, they are physical magnitudes that fully satisfy the technical and economic conditions of the system for a given instant (think of optimal dispatch and economic operation of the generating park, adequate levels of loadability on the lines, acceptable levels of tension on the bars, etc.).
To ensure that the power flows respond faithfully to the actual operation of the SEN for a given instant of time, the real generation and demand data were downloaded from the Coordinator's public information platform on February 28, 2018 at 14:00 hrs. (which was required as an instant to define the state of the system). Subsequently, an Excel spreadsheet which included the most relevant generators and loads was generated, prioritizing of the most used lines at that time.

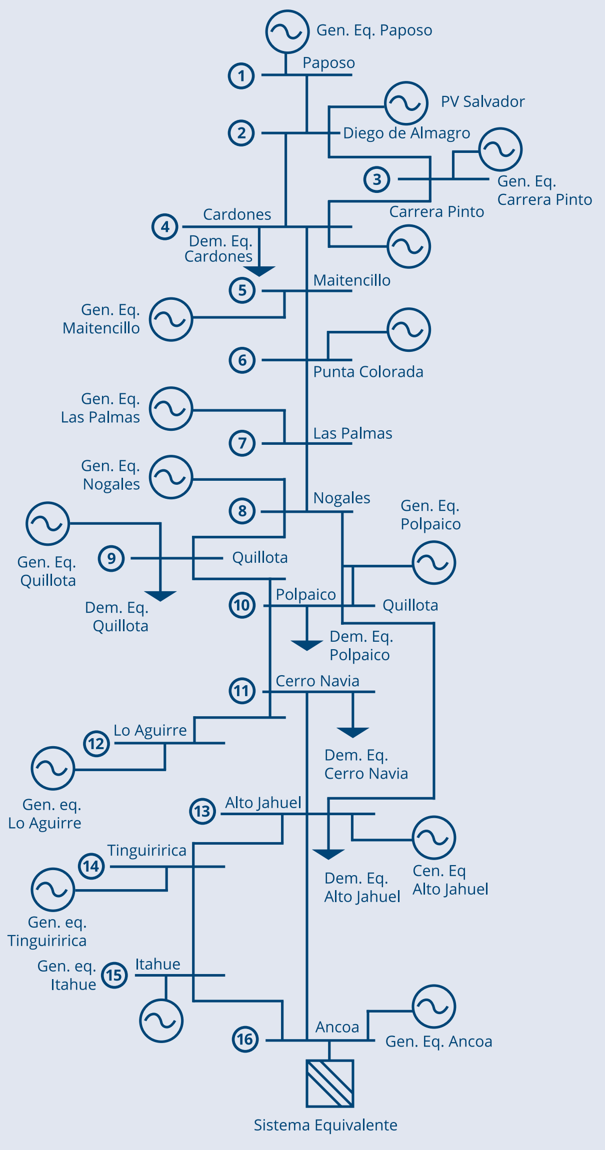
To complete the electricity supply chain in accordance with the current Chilean regulation (article 115° of Law 20.936) of the Ministry of Energy (2016), the losses were assigned to the final customers (Rudnick, 2015), so the traceability methodologies studied were:

- Bialek's method using Coarse Flows (Bialek, 1996)
- Postage Stamping Method (D. Kirschen & G. Strbac, 2004)

Then, with the shrunk SEN scheme shown in Figure 4 and the input data shown in Table 1, an AC power flow was run in DigSilent PF to obtain the information needed to apply the selected methodologies. In this regard, although Bialek's Gross Flows allow the construction of a complete supply chain, the instantaneous application of this method translates into an enormous challenge in terms of implementation, since, in order to experimentally trace flows between the Salvador PV plant and the final client in Santiago, it would be necessary to have access in real time to the total amount of meters that the Coordinator has available at the national and zonal transmission levels, in addition to all the information rising from the instantaneous load flow at the distribution level.

On the other hand, the proportional distribution of losses through the postal stamping method has the virtue of being an extremely simple and evident procedure, which brings great advantages in terms of implementation, since only the instantaneous global generation, global demand and punctual withdrawal data needs to be obtained. However, this mechanism alone cannot build a supply chain and its execution at the systemic level leads to significant economic distortions in terms of line use attribution, especially in large radial networks with a heterogeneous spatial distribution of producers and consumers, as occurs, for example, at the Chilean transmission level.

Figure 4: Reduced SEN. PV Salvador is connected at busbar 2 and the end customer at bar 11



Source: Phineal, 2019

Table 1: Allocation of losses to SEN charges for 14:00 hrs. on February 28, 2018. End customer connected to bar 11

	Input data		Output data
Busbar	Generation (MW)	Demand (MW)	Losses by Postage Stamp Method (MW)
1	253,07	0,00	0,00
2	62,56	0,00	0,00
3	212,08	0,00	0,00
4	83,07	168,39	11,95
5	222,00	0,00	0,00
6	262,05	0,00	0,00
7	48,27	0,00	0,00
8	818,00	0,00	0,00
9	1445,00	812,60	57,67
10	149,57	179,25	12,72
11	0,00	1979,16	140,47
12	117,00	0,00	0,00
13	190,33	1368,05	97,09
14	210,80	0,00	0,00
15	215,00	0,00	0,00
16	556,90	17,13	1,22
Total (MW)	4845,70	4524,58	321,12
Losses (MW)	321,12		

Source: Phineal, 2019

After comparing the virtues and challenges of the selected methodologies, the postage stamp method was chosen to be part of the constraints of the DApp, which for a certain moment of time t establishes:

$$P_{losses\,k} = \frac{D_k}{D_{total}} \cdot P_{losses\ total}$$

Where:

P_{losses_k}:	allocation of electricity losses to the demand connected to the system's k-busbar
D_k:	demand connected to the k-busbar
D_{total}:	total demand on reduced SEN
$P_{lossestotal}$:	total electricity losses of the reduced SEN, equal to: $P_{losses\ total} = G_{total} - D_{total}$
G_{total}:	total generation on reduced SEN

The results of the proportional allocation of losses are shown in Table 1, which shows that the loads that withdraw the most are also those that produce the greatest amount of losses in the transmission lines of the SEN.

One of the reasons for choosing this methodology is the simplicity of the calculation, which allows the end user to understand, for a given instant of time, how many physical losses are being assigned regardless of the connection point. In effect, although the end customer "k" is connected to the distribution network in Santiago (which is an electricity subsystem within the "Cerro Navia" load connected to the busbar 11 of the reduced SEN in Figure 4), equation (1) can also be reproduced, so that:

$$P_{losses_k} = \frac{D_{CerroNavia}}{D_{total}} \cdot \frac{D_k}{D_{CerroNavia}} \cdot (G_{total} - D_{total}) = \frac{D_k}{D_{total}} \cdot P_{losses\ total}$$

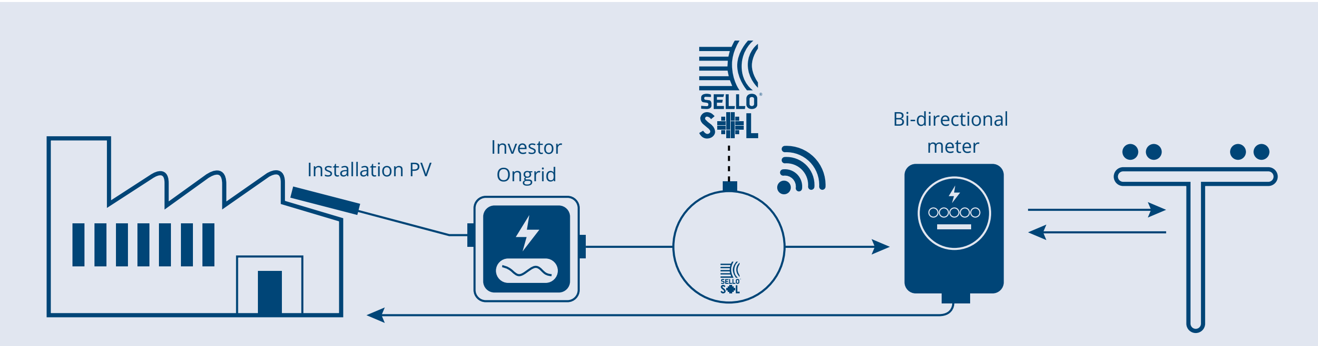
As electricity losses are "non-linear", the use of the above equation imposes the challenge of improving the sampling frequency of the processed data (to the order of minutes or seconds), since this is the only way for the dApp to obtain a more reliable representation of the losses produced by each SEN load over time, even when the reach of such physical objective is impossible.

A second reason is that the transactional cost of validating operations in Ethereum (2015) reveals that it would be more convenient to write simple functions in the smart contract because the computational effort is lower, lowering the costs for each file execution (storage in memory, calculation speed, etc.).

Project Status: smart contract programming and dApp -GTIME development

In order to build a real-time electricity supply chain using blockchain, it has been decided to create a smart contract that would serve as a DApp "manager" were operations would be performed on a local server, but with data validated by both the GTIME blockchain and Ethereum. It is intended to extract the measurement of energy injected by PV Salvador (Gk) and to measure the energy consumed by the end load (Dk) from the GTIME blockchain based solar certification platform Sello Sol, as in Figure 5. On the other hand, the data of total generated energy (Gtotal) and total energy demand (Dtotal) are extracted from the "Energía Abierta" platform of the Comisión Nacional de Energía (2019), where the SEN data is certified using Ethereum.

Figure 5: Generation measurement through phiNergy for Sello Sol platform, based on GTIME



Source: Phineal, 2018

Solidity language[4] in its 0.4.24 version was used for the smart contract programming, and the first data recording and calculation tests were carried out in Remix. With these tests it has been determined that instead of the metering nodes (phiNet and phiNergy) uploading the measured information to the smart contract and the GTIME blockchain simultaneously, it was better to use an "oracle" service that managed to import the certified data from the Sello Sol platform but, at the same time, the "oracle" would not become an intermediary that would have to be trusted.

Among the available alternatives, Oraclize was chosen, which through its "authenticity tests" based on auditable virtual machines, enables any smart contract to access Application Programming Interfaces (API) data or websites securely. According to the official website (Oraclize, 2018), depending on the developer's needs, "authenticity tests" can be of four types: TLSNotary Proof, Android Proof, Ledger Proof and Storage and Delivery.

Each of these tests can be requested from a smart contract to corroborate that the information extracted from an external database to a blockchain is reliable. The query can be recorded within the contract "builder", or specifically in some line of the code. In addition, together with the "proof of authenticity", Oraclize provides a "proof of storage" (proofStorage in Figure 6) that takes care of loading and saving the callback in IPFS, which is a P2P protocol and file system that replaces the traditional HTTP protocols with a distributed web (IPFS, 2018). With this, it is possible to get the amount of energy generated in the Gk plant and the amount of energy withdrawn by the end customer Dk by importing the contract "usingOraclize.sol" into the code of our smart contract (see Figure 6). In this way, for an instant of time t, Oraclize will detect the "events" that are programmed and will deliver the data certified by the GTIME blockchain in real time to be used in the supply chain.

[4] Programming language for smart contracts.

Figure 6: Segments of the energy traceability DApp using Oraclize, Ethereum and the GTIME Blockchain

EnergyTraceability.sol × | app.js

```
pragma solidity ^0.4.25;
import "installed_contracts/oraclize-api/contracts/usingOraclize.sol";

contract EnergyTraceability is usingOraclize {

    address public owner;
    string public vectorEnergy;
    string public vectorLosses;
    bytes32 queryId1;
    bytes32 queryId2;
    mapping(bytes32=>bool) validIds;


    event newOraclizeQuery(string description);
    event LogEnergyUpdate(string energy);
    event LogLossesUpdate(string losses);
    event LogUpdate(address indexed _owner, uint indexed _balance);


//-----------------------------------------CONSTRUCTOR-------------------------------------------------

    constructor() payable public{

    owner = msg.sender;

    emit LogUpdate(owner, address(this).balance);

    oraclize_setCustomGasPrice(4000000000);

```

EnergyTraceability.sol | app.js ×

```

        //Cálculos sobre Cerro Navia (barra 11). Se redondea la cuantía racional a tres decimales

        //Datos necesarios para Cadena de Suministro a nivel de transmisión nacional
        var Gen_2_11 = document.getElementById("G_2-11");
        G_2_11 = (K_G2 * G_2).toFixed(3);
        Gen_2_11.innerHTML = G_2_11; //Contribución de PV Salvador a Cerro Navia

        console.log(G_2_11);

        var Plosses_11 = document.getElementById("Plosses11");
        P_losses_11 = (D_gross - D_real).toFixed(3);
        Plosses_11.innerHTML = P_losses_11; //Pérdidas locales en Cerro Navia según Flujos Gruesos

        var Plosses_11_2 = document.getElementById("Plosses11-2");
        P_losses_11_2 = ((G_2_11 / D_gross) * P_losses_11).toFixed(3);
        Plosses_11_2.innerHTML = P_losses_11_2; //Pérdidas de abastecimiento desde PV Salvador

        var Dreal_11_2 = document.getElementById("Dreal11-2");
        D_real_11_2 = ((G_2_11) - (P_losses_11_2)).toFixed(3);
        Dreal_11_2.innerHTML = D_real_11_2; //Demanda en Cerro Navia alimentada por PV Salvador


        //Datos necesarios para Cadena de Suministro a nivel de transmisión zonal y distribución
        var KD11 = document.getElementById("k_D11");
        K_D11 = (D_cliente / D_real_11_2).toFixed(3);
        KD11.innerHTML = K_D11; //Factor de contribución en consumo: Cliente -> Cerro Navia

        var Gen_Cliente = document.getElementById("GCliente");
```

Source: Phineal, 2019

On the other hand, in order to obtain the total generation data G_{total} and total demand D_{total} (which will clear the total losses $P_{losses total}$), the dApp uses another JavaScript file to make a "request RESTful" on the "*Energía Abierta*" platform, as recommended by the institution in its web page (2019).

With the known figures, and due to the fact that the solidity language still has limitations to work with rational numbers, it has been decided to perform the calculations in the JavaScript file "app.js", which receives the data consulted in string format and transforms them into rational numbers (see Figure 6). It then operates according to the postage stamp method to form an instantaneous supply chain, publishing the result of the calculation through an HTML link. By this, the smart contract runs itself reconstructing a supply chain for each query instant (t), with two levels of validation in the source data: the GTIME federated certification and the Ethereum public certification.

Finally, through the remainder of the project development, it is intended to program the reinstatement of the data that compose the instantaneous supply chain to the smart contract, so that the traceability vector between PV Salvador and the end client: $\{G_k;P_{losses_k};D_k\}$, also receives a transaction hash in Ethereum validating the supply chain.

V. Conclusion

Throughout the electricity supply chain there are various stakeholders, such as generation companies, transmission companies, distribution and marketing companies, which act as intermediaries between the production and consumption of electricity in its traditional format, increasing supply costs both for technical reasons (losses associated with transport) and commercial reasons (type of customer, type of tariff, etc.). At the same time, environmental awareness and the commitments of countries to face climate change, the consolidation of generation technologies using renewable energies, energy storage, electromobility, the irruption of IoT and citizens' demands for greater transparency in energy processes, is pushing companies and institutions to replace the current model for a more decentralized and proactive model.

Figure 7: Sello Sol

Source: Phineal, 2018

In this context, platforms such as Sello Sol, which have a blockchain certification for production and consumption, are close to guaranteeing the supply chain of "solar electricity" with two levels of validation, not only opening the door to begin the energy decentralization, but also to certify the confection of goods with more "green attributes", as well as to enhance the differentiation of products and services achieved through the use of solar energy, by showing the amount of CO2 mitigated when manufacturing a product or carrying out a service.

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