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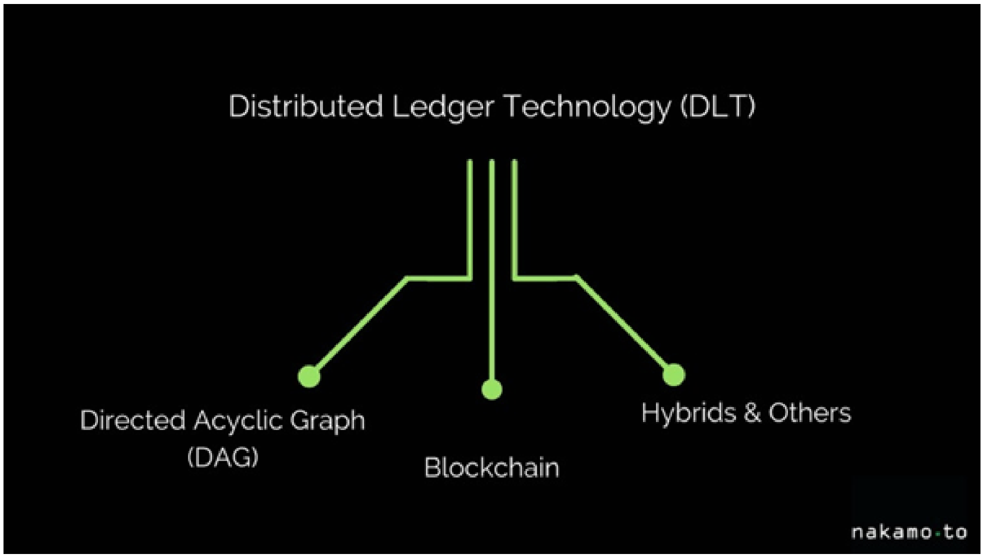
15 minutes of reading

Economic outlook

Issues and Foresight

The news has covered bitcoin, ethereum, blockchain, cryptocurrency for several years now. Digital currencies and more broadly blockchain are innovative tools in the digital age. Blockchain has the potential to be a valuable new tool for many sectors, including energy. So, what exactly is blockchain technology? How can one arbitrate between its different uses? How can blockchain accelerate the energy transition? Is it ultimately possible to ensure a sustainable and green future from this emerging technology?

The rise of cryptocurrencies such as **Bitcoin** and **Ethereum** has drawn focus to **blockchain**, a **Distributed Ledger Technology** (DLT). It is important to make a clear distinction between **cryptocurrencies** and blockchain to avoid any confusion. Bitcoin is a cryptocurrency that uses blockchain as its foundation technology. There are now 4,894 cryptocurrencies[1] that are based on blockchain or DLT technologies. Technologies that store, distribute and facilitate the exchange of value between users are called DLTs. A distributed ledger is a decentralized database which is distributed across multiple nodes[2]. Nodes maintain the ledger on which the transactions are recorded. There is no central authority as every node has an equal status which makes the technology transparent. A transaction is verified by the node based on the consensus algorithm or voting mechanism. Nodes which solve the algorithm are able to participate and approve transactions. This technology is tamper-free as it does not involve a central authority.



Source: Nakomo.to

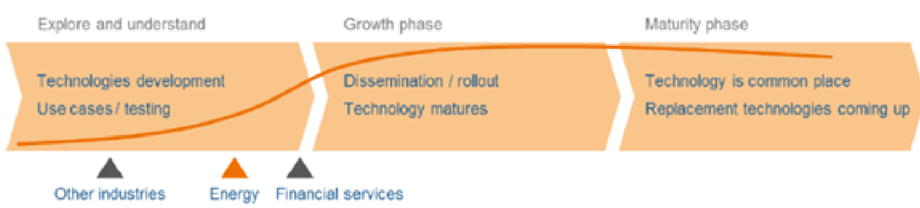
Figure 1: Distributed Ledger Technology

Blockchain is the first fully functional DLT. No block on a Blockchain can be altered or removed once verified by a node. There are many different blockchains. For example, **Bitcoin's blockchain** is different from Ethereum's but both these underlying blockchains or versions of them are used for other projects, not just for their own native cryptocurrencies. There are others besides. Different blockchains can have distinct consensus protocols and algorithms which are used for verifying transactions. **Proof of Stake** (PoS) and **Proof of Work**[3] (PoW) are the two most common consensus protocols to date, though others are emerging. Blockchain is a distributed ledger that has become the technology behind cryptocurrencies (Bitcoin, Ethereum, Ripple etc). It differs from other DLTs in terms of architecture; however, the underlying principle is the same. Emerging technologies like blockchain have a key role to play in energy transition and to achieve the Paris climate goal of 1.5 degree, as they have the potential to become a technological bridge towards the energy transition of the 21st century. To evade climate risk, the net carbon emissions of our planet need to be zero by 2050 limiting global warming to 1.5 °C. This need has accelerated energy transition towards decarbonization, digitization, and decentralization. In 2018, 171 GW of renewable power capacity was added to the global grid[4]. **R enewable Energy Sources** (RES) are intermittent (except hydropower) and difficult to predict as they depend on weather conditions which make the management and operation of electricity systems and networks difficult. This has an effect on the power grid and the underlying markets. Additionally, the existing structure of energy and electricity markets almost excludes small players' participation in the markets and incentives for active consumer participation are insufficient[(1)].

Therefore, flexibility, inclusiveness, and structured incentives are key to improved, secured, safe and stable operation of the power grid and electricity markets. Some measures to ensure flexibility are the integration of supply–demand response and energy storage services. Current energy systems are quickly transforming with the expansion of distributed energy systems (DES) where the production of energy is no longer centralized but originates from multiple nodes on the grid including contributions from consumers who produce energy (prosumers). DES which includes local renewable sources and energy storage are advancing quickly with technical innovation. The future of DES requires an exchange between quickly expanding smart devices[5] communicating in real-time and prosumers (both producers and consumers). This is contrary to the traditional market structure which is centralized and therefore the expansion of DES cannot be managed with the existing technologies and infrastructure. It is clear that future growth will rely on information and communication technologies (ICT) to mediate more sustainable and distributed energy(2). The integration of ICT with energy networks has resulted in improved efficiency and better resource coordination for ‘physical and financial flows in smart grids”. The next-generation smart grid is coined as the “**energy internet**”. The energy internet is a web of connected smart devices, information and physical flows, big data, cloud computing, and artificial intelligence which facilitates interconnection and energy coupling from multiple sources. Blockchain technology can facilitate this transition towards the energy internet as the technology is irreversible[6], incorruptible and decentralized. Therefore, blockchain can enable safe, transparent and distributed prosumer markets as well as traditional renewable markets. The technology can support emerging microgrids involving prosumers and can solve issues related to consensus, security, and flexibility in the “energy internet”(3). Given the promising prospects of the technology, a number of use cases have emerged which aim to disrupt the energy sector. As per an internal study of IFPEN[7], 285 projects have been identified out of which 215 are related to energy and 70 to the environment. 50% of the energy projects concern renewables and energy trading. Many energy companies especially utilities have taken interest in exploring the potential benefits of distributed ledger technologies (DLT), as an enabling technology for low-carbon transition and sustainability. In this report, we explore the key use cases within the energy sector that have the potential to radically change and redefine the energy markets of tomorrow.

BLOCKCHAIN, ENERGY AND INVESTMENTS

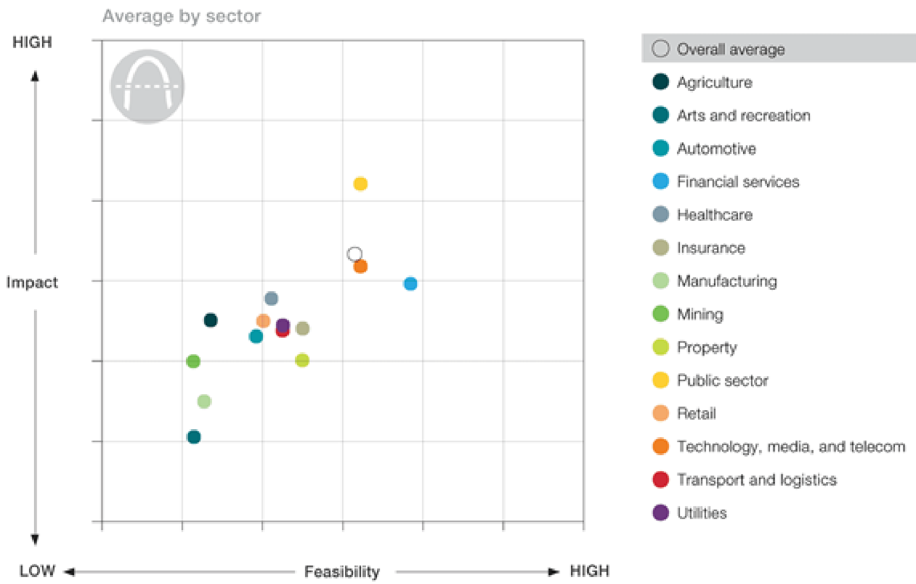
There has been significant progress over the last two years with regards to blockchain use cases in the energy sector.



Source: World Energy Council

Figure 2: Different phases of blockchain technology development

The application of blockchain in this sector is currently being explored and we are slowly making a move forward to enter a growth phase (Fig. 1). The current market is filled with a number of use cases, pilot projects, and startups which have begun to investigate the possibility of integrating blockchain technology within the existing energy market with the aim of improving efficiency and reducing costs. However, we are yet to see a commercially successful business in the energy blockchain space.



Source: Mckinsey

Figure 3: Blockchain opportunities by industrial sector

An in depth analysis by Mckinsey (Fig. 3) of blockchain use cases from various industries revealed that certain sectors like Public sector, Financial services, Technology, Media and Telecom are more feasible and impactful than the rest. Under the Utility sector, the use case of renewable energy certificates has turned out to be highly feasible and impactful[8].

The global market for blockchain and associated technologies is estimated between $5.4 bn (Allied Market Research) and $28.4 bn (IHS Markit). The market is expected to post an annual growth between 50 – 75% annually. This reflects the rapid digital transformation, with blockchain, of industries across different sectors including energy during the next decade.

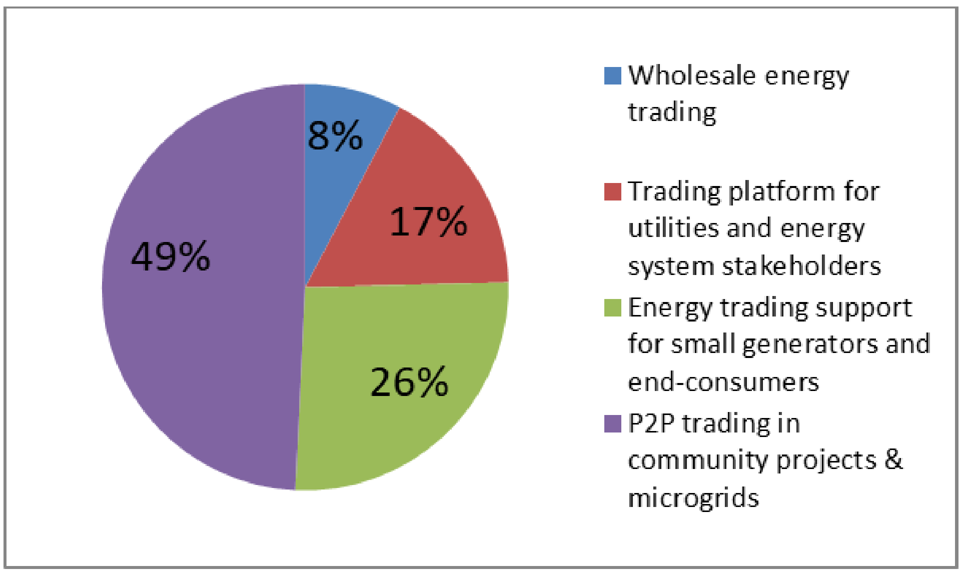
The industry has raised nearly $23.7 billion dollars since 2013 across 3,738 companies globally. 75% of these investments are early stage i.e. pre-seed, seed or angel investment round[9]. In addition to this financing, initial coin offerings (ICOs) and the more recent initial exchange offerings (IEOs), which are unique methods of crowdfunding, are aimed at investors (mostly retail investors) who are willing to purchase digital tokens in exchange of investment. These fundraising models allow startups in the blockchain space to ignore any equity commitment, as investors buy issued digital tokens or cryptocurrencies that are native to the principal technology behind the company's product.

BLOCKCHAIN APPLICATIONS IN THE ENERGY SECTOR

Trading/transactive energy

As per the National Institute of Standards and Technology of the US Department of Commerce, **transactive energy** is a “system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.”
Blockchain’s link to transactive energy comes from its **peer to peer (P2P) exchange of value concept**. In the same manner that financial transactions can be validated via a P2P method, energy transactions can be decentralized through a P2P method which basically evolves into P2P energy transfer. The idea that power generation and consumption can be fully decentralized through blockchain is a disruptive change in contrast to the conventional centralized exchange and trading of energy.

Given the promising benefits that blockchain offers to transactive energy, many partnerships have been formed to work on this and many projects have already been planned, tested or implemented. A total of 65 projects have been identified and categorized into Wholesale trading, Trading platforms for utilities and energy tokens, Energy trading support for small generators and end consumers and P2P trading in community projects and microgrids (Fig. 3). Nearly half of the total projects are focused on wholesale energy trading. Geographically, 60% of the projects are concentrated in Europe followed by 14% in North America and Asia each[10].



Source: IFPEN[11]

Figure 4: Different applications under energy trading

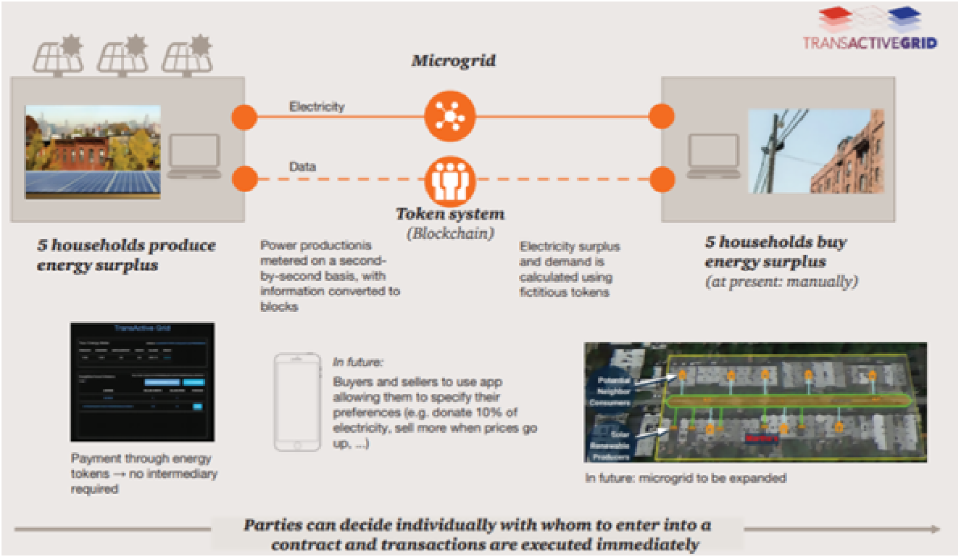
In Germany, **Enerchain** is a project to develop “Wholesale Trading” which is to deploy a technical infrastructure, allowing participants in the energy wholesale markets to trade power and gas in a decentralized way, thus avoiding intermediaries and central market platforms. The proof of concept was started in May 2017 with 44 leading European energy trading companies. The participants have already been part of live trades, which were publicly executed during the ongoing project phase. On 20th May 2019, the Enerchain 1.0 platform was launched. It is the first blockchain-based distributed trading platform enabling OTC energy trading of spot and forward contracts in the power and gas markets.

The project promises lower operational costs[12] as it is a decentralized system in which roles such as management, market control, market supervision, legal, regulation, compliance, support, IT, marketing and sales either do not apply at all or are very limited. Also, the underlying framework of the Enerchain platform offers a fast blockchain environment which compliments trading processes that require speedy data synchronization between participants. Given its trading capability within energy communities (P2P), flexibility between distribution grids and wholesale delivery at the level of balancing zones, it could become a leading trading infrastructure for emerging markets[13].

In France, **Sunchain**, a blockchain startup backed by Enedis provides an opportunity to **Photovoltaic (PV) plant owners** within the same region to trade with each other. It utilizes blockchain and **Internet of Things** (IoT) devices to manage energy exchange within local energy communities connecting producers, consumers and prosumers (P2P trading). IoT based smart meters gather and record production and consumption data on the Sunchain blockchain where it is encrypted, signed and recorded[14].

In the Netherlands, **PowerToShare** and **Powerpeers** are similar companies that provide platforms for the P2P sharing and trading of electricity.
Wepower, an Estonia based startup provides “Energy trading support for producers and consumers”. It is a blockchain-based green energy procurement and trading platform which brings together renewable energy generators and investors interested in supporting global green energy projects. Renewable energy produced is tokenized and subsequently traded through the platform. It can be exchanged for fiat currencies or cryptocurrencies. In Q4 2018, "WePower tokenized a year’s worth of Estonian grid data (26,000 hours and 24 terawatt-hours of aggregated production and consumption data to blockchain) into 39 billion smart energy tokens. The pilot project is said to have been the largest of its kind in the world. Each token is essentially a digital self-settling power-purchase contract representing one kilowatt-hour of power. The tokens are tradable and can be sold into the local energy wholesale market by linking the digital contracts with power grid data on the Blockchain."

Power Ledger is an Australian blockchain startup that has partnered with renewable energy companies like Nest Energy, Origin Energy, and Project Brainstorm to bring P2P trading to Australian residents. It provides utility companies and stakeholders with a trading platform to exchange renewable energy and carbon credits, and for the reporting and verification of carbon and renewable energy credits. The company has active commercial or trial deals in Australia, the United States, Japan, Malaysia, Thailand, Austria, and India for the use of their software[15].



Source: PWC

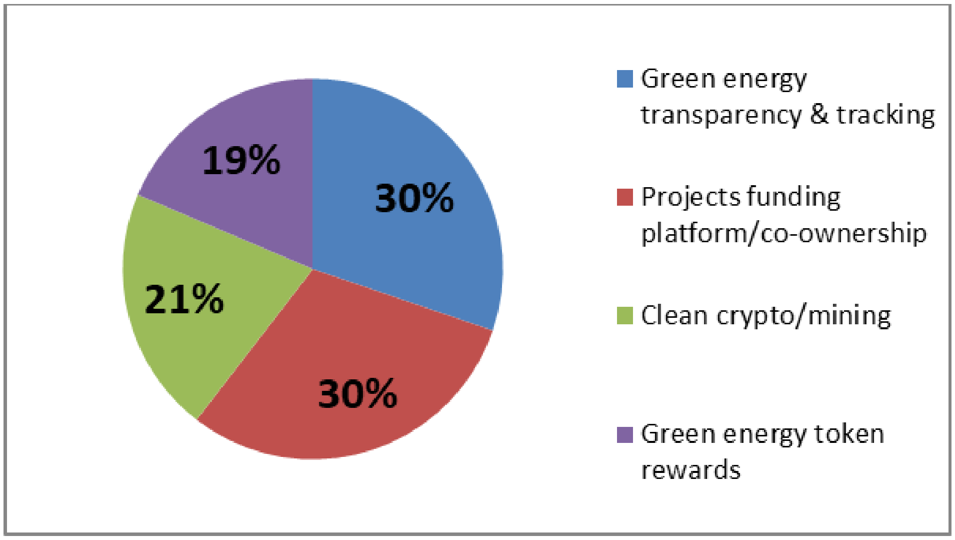
Figure 5: The Brooklyn microgrid project

In the United States, LO3 Energy has already implemented the famous "**Brooklyn Microgrid**" pilot project in collaboration with Siemens. Under this project, a community in Brooklyn can directly use LO3's P2P platform for energy trading. The platform enables prosumers to directly sell excess solar electricity to neighbors and contribute to the local economy.

The project (Fig. 4) aims to create a local community market for renewable energy in order to test consumer preference when they are given an option to trade their excess energy locally. Prosumers have the option to market their product in addition to feeding excess energy back to the grid.

Renewable Energy

A total of 43 projects in our database have been identified within Green/Renewable Energy (Fig. 5) with applications ranging from Green energy transparency and tracking to Project funding, and Clean crypto/mining and Green energy token rewards. Geographically, 47% of the projects are concentrated in Europe followed by nearly 30% in North America[16].



Source: IFPEN[17]

Figure 6: Different applications under renewable energy

In addition to individual projects, companies are coming together to create new joint communities to explore the role of blockchain in energy. For Example, Energy Web Foundation (EWF), is a global non-profit organization focused on accelerating blockchain technology across the energy sector. It is working on three technologies, EW Origin, EW Link and the Energy Web.

EW Origin is aimed at growing renewable energy markets and increasing efficiency of carbon trading with SDKs (Software Development Kits) that simplify and enhance the issuance, ownership tracking, and buying/selling of renewable energy certificates (RECs), guarantees of origin (GOs), and related green attribute products. EW Origin records the provenance and automatically tracks the ownership of renewably generated electricity with unprecedented transparency, integrity, and detail—including location, time, source type, and CO_2 emissions. Real-world test pilots will ensure that the developed technology stack meets market and regulatory needs across the globe.

The **Energy Web** (developed by the EWF community) is an open-source, scalable blockchain platform specifically designed for the energy sector's regulatory, operational, and market needs. The open-source platform serves as a host for decentralized applications supporting distributed and renewable energy-focused business models. It fulfills the need for foundational, shared, digital infrastructure for the energy and blockchain community to build and run their solutions. The applications will range from improved grid access and management to effective processing of certificates of origin for renewable power. This platform will be based on the **Proof of Authority (PoA) blockchain consensus mechanism1**[8]. The "authorities" will be the companies that have partnered with EWF as EWF affiliates. The validating system under this mechanism can address the technical and regulatory challenges for the implementation of blockchain in the energy sector.

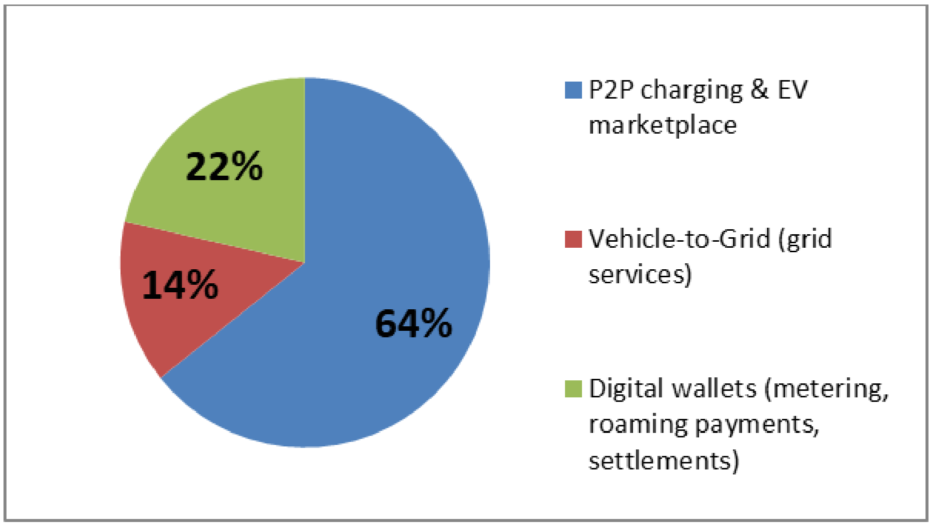
Eventually, the number of authorities is expected to exceed 1,000 and EWF will put in place a governance system to disincentivize malicious behavior to an extent which may lead to the removal of an authority.

Swytch, a non-profit foundation based in Zug, Switzerland gives organizations "a complete and accurate view of their energy generation, energy use, and associated carbon offset information." The

Swytch platform enables token-based incentives, open-source data aggregation, and has unique blockchain protocols to secure and verify energy production data. The decentralized platform certifies and rewards sustainability efforts with Swytch tokens, efforts which are evidenced by smart meter data, IoT devices, EVs, and storage systems used to reduce CO_2 emissions. Swytch tokens will be created in an energy-efficient permissioned blockchain environment that avoids proof of work mechanisms[(1)19].

E-Mobility

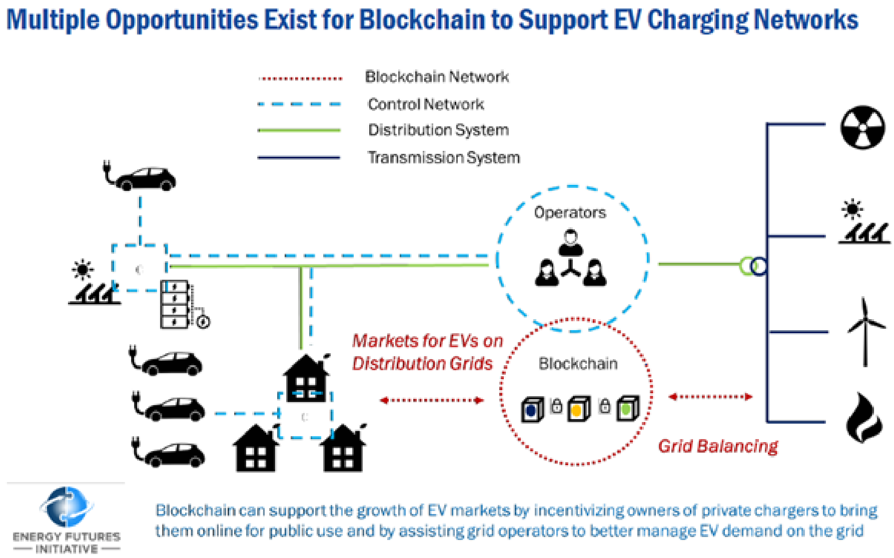
There are 14 projects related to e–mobility which have been identified and categorized into P2P Charging and EV marketplace, Vehicle to grid and Digital wallets (metering, roaming payments, settlements). Nearly 65% of the projects are related to P2P charging and the EV marketplace with 70% of the projects concentrated in Europe[20].



Source: IFPEN[21]

Figure 7: Different applications under e-mobility

In Germany, the utility major RWE along with Ethereum based startup Slock is collaborating on a project to innovate charging infrastructure. This project, named Share&Charge allows private individuals to rent charging stations owned by them in a P2P (Fig. 7) way. This may result in the wider availability of EV charging infrastructure in an immediate vicinity and create access to an affordable and reliable payment solution. The Share&Charge application, based on the Ethereum blockchain, can be downloaded on a smartphone. All transactions can be tracked by any member of the network. The platform achieves automated billing and can incentivize the private building of EV charging infrastructure as charging stations generate a revenue stream for owners through enabling other drivers to charge EVs at their points. RWE has already launched 1,200 stations which are connected via this application. The owner of a charging station can set the price by opting flat, time based or electricity price-based rates. Share&Charge manages and records all payments and charging data and connects customers to the charging station network. The company also plans to facilitate seamless payments by integrating its stable coin[22] as part of the payment solution.



Source: Energy Futures Initiate

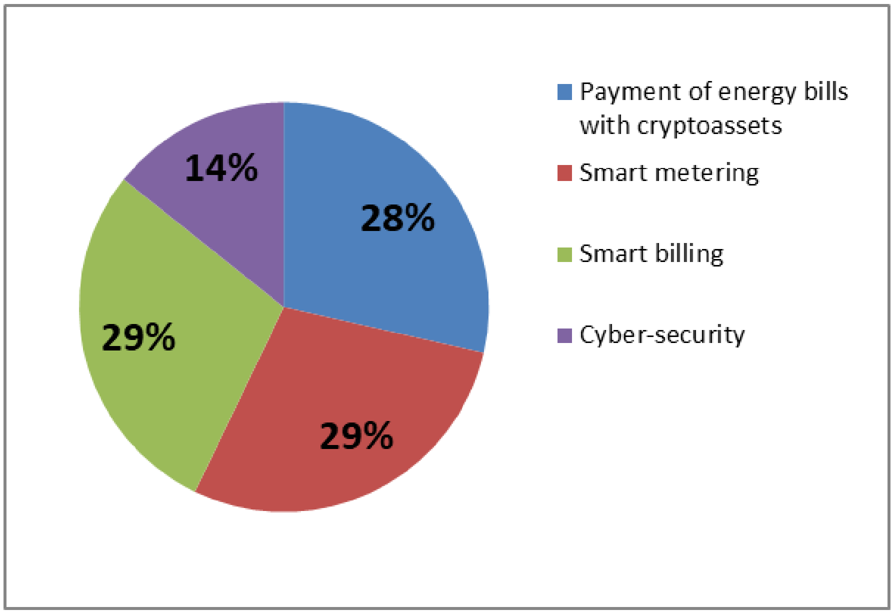
Figure 8: Blockchain opportunities for the EV charging network

To summarize, blockchain can incentivize private individuals via integrating private chargers to the grid for public use and it can assist the operators to better manage the demand. Despite the recent progress, challenges remain for a widespread deployment of blockchain application for EV infrastructure. The challenges range from consumer to household to local level under which offering private charging stations for public use can lead to privacy and zoning issues, creating a barrier to entry. Also, logistical issues arise if a private charger contributes to congestion at its home, office, local street or parking space location.

Smart Metering

A total of 21 projects have been identified under **Smart metering solutions** (Fig. 8) with applications ranging from Smart metering, Smart billing, Cyber security and Payment of bills via cryptocurrency. Geographically, 70% of the projects are concentrated in Europe followed by nearly 12% in North America[23].

The **E-Prosume** project is a partnership between Evolvere (Italian aggregator) and Prosume. In August 2018, Mangrovia Blockchain Solutions (a software house specializing in applied cryptography technology) joined the project, which aims to provide prosumers with new services enabled by the platform, such as smart billing and smart payments.



Source: IFPEN[24]

Figure 9: Different applications under smart metering

In France, Engie is developing another smart metering solution in partnership with Ledger, a French Blockchain hardware startup. Together they plan to develop a secured, autonomous and blockchain agnostic "oracle" (a hardware device that will be compatible with most blockchains). The so-called hardware oracle will measure data at the source of green energy production (such as wind turbines, solar panels or hydropower) and safely record it on the blockchain to be used in decentralized applications. In April 2019, Engie tested prototypes on some of its renewable infrastructures and plans to install 100,000 boxes on wind, solar and hydro farms by 2023.

The hardware is compatible with the Ethereum Blockchain and the Energy Web Foundation Blockchain. The solution will eventually become completely platform agnostic in order to be used with any blockchain. The device will be able to connect different blockchains and several decentralized applications at the same time. As security is key to having trustworthy data, the device will include a secure element and an anti-tampering solution[25].

CHALLENGES, OPPORTUNITIES AND FUTURE OF BLOCKCHAIN APPLICATIONS

The limitations of blockchain technology in energy can range from technology, economics, environment to public adaptation.

Tech & Economics

Early blockchain technology adopters face the challenge of selecting the right consensus mechanism and system architecture. The future evolution of these technologies is still not clear and often during a blockchain's testing phase, the developers may face critical issues which can result in a change of its underlying mechanisms conducted via a hardfork to a new version of the network[26].

Current energy trading systems can record energy transactions in conventional databases but cannot offer immutability of records or transparency[(1)]. Also, the existing distribution grid networks only facilitate selling excess energy at a pre-determined FIT (Feed in Tariff) to the utility company but not to the consumer directly. This can be achieved by blockchain technology, integrated along with ICT equipment or IoT devices (smart meters) and artificial intelligence (AI) which can also improve predictive analysis and help in balancing the energy demand and supply and manage peak power to avoid technical burdens and costly network reinforcements. However, hardware and energy costs related to validation and verification of data are high as many energy pilots' projects use PoW consensus which is energy-intensive. The calculation, transmission and storage of information on the blockchain ledger with PoW consensus requires massive amounts of energy consumed by individual computing units scattered globally. This can be illustrated by the annual electrical footprint of bitcoin mining which is estimated between 45 Twh (MIT) to 73 Twh (Digiconomist). This can be compared to the whole of Austria's electricity consumption. In addition, Bitcoin mining's annual carbon footprint (34.73 Mt CO_2) is comparable to that of Denmark27. Bitcoin is just one PoW blockchain among others.

Therefore, the energy footprint is a consideration when it comes to the implementation of the technology. This energy intensive mining is dominated by mainly two types of hardware miner – GPU and ASIC miners. The ASIC miners can only mine a specific algorithm, for example, Bitcoin or Ethereum. However, ASIC miners have high efficiency and better processing power than GPU's.

In addition to energy intensity, scalability and speed remain key challenges that can hinder the growth of energy projects aiming to deploy blockchain technology.

However, the advancement of new consensus mechanisms like PoS, **PoA and Practical Byzantine Fault Tolerance**[28] (PBFT) have the potential to resolve such issues. For example, PoS, as opposed to PoW, does not require specific hardware and verifies a new block transaction based on assets or owned cryptocurrency units (stake), thereby avoiding high energy consumption. EWF which uses a PoA validating system may address the technical and regulatory challenges of implementing blockchain in the energy sector. The average demand for an authority node on the EWF network is approximately 78 watts, which is equivalent of a normal household incandescent bulb. Given that there are 46 authority nodes as of now, the total energy demand is approximately 3.6 kW. Additionally, the mechanism is expected to improve performance and security as regulators will have knowledge about the controlling "authorities." It is quite unclear how the energy usage for cryptocurrency mining will evolve in the near future as the technology is constantly changing and regulations are evolving, however, the EWF network could be a faster, more energy efficient, secured platform for participants.

Proof of Identity (PoI), undertakes hash-based user identification, requiring lower CPU, energy consumption, and transaction costs than PoW. This consensus mechanism could prove to be more suitable for private or semiprivate networks with selective access in local energy markets. A private blockchain comprises of limited number of members and it is managed only by those members while in a semi-private blockchain, a single entity grants access to any qualifying user[(2)].

As all these developing technologies mature, the best fit to the energy sector is expected to improve energy efficiency, scalability, security and speed.

Social

The social aspect of the blockchain deals with uncertainties in behavioral change, public acceptance, stakeholder management, and skill development. Active engagement of residential prosumers is key to scale up the P2P platform. Also, people are more likely to purchase renewable energy if assured of its origins, according to green marketing theory.

Therefore, transparency, certificates of origin, and data immutability on blockchain platforms can increase consumer confidence. In the long term, blockchain and enhanced traceability can support user choice. However, increased choice may not necessarily lead to behavioral change[(3)].

Policy and Regulations

Policy and regulations are key to scaling and adoption of blockchain in the energy sector. P2P trading faces challenges in balancing integration with central controls, and coordination with the main grid. Additionally, with the expansion of decentralization, the management of energy systems get complex which may lead to an acceleration of grid defection or underutilization of network assets[(1)]. These issues require significant regulatory changes as the way in which services are offered to the consumers will change drastically.

Electricity tariffs in the current market structure are still heavily regulated and therefore a new framework which can support flexible tariffs based on smart contracts is needed. This can greatly aid local or microgrid energy markets to be integrated with the main grid and be a part of the regulated system. The work on regulations has already started in many countries globally. For example, In Japan, the 5th Science and Technology Basic Plan (2016–2020), supports the advancement of smart meters and ICT infrastructures. Grid connection technologies for renewable energy, power quality, and microgrids have been key government-driven areas. While developments have been made in collaboration with the Japanese industry and local administrations, the central government remains the key decision-maker[(3)]. In Europe, the European Commission aims at positioning Europe at the forefront of blockchain innovation and adoption. Therefore, to build a transparent regulatory framework, the commission has worked on three strategic initiatives[29].

• The **European Blockchain Partnership**, created in April 2018, joins at a political level all EU Member States and members of the European Economic Area (Norway and Liechtenstein). The signatories of this declaration will work together towards realizing the potential of blockchain-based services for the benefit of citizens, society, and economy.

• To facilitate public-private cooperation, the **International Association for Trusted Blockchain Applications** (INATBA) was formed in April 2019. This association brings together suppliers and users of Distributed Ledger Technologies with representatives of governmental organizations and standard setting bodies from all over the world.

• The European Commission in collaboration with the European parliament also launched the **European Blockchain Observatory and Forum** which acts as a stakeholders engagement platform, an initiative to accelerate blockchain innovation and uptake, by featuring, knowledge sharing, community engagement, project mapping, working groups on use cases and the regulatory framework, production of thematic reports and delivery of training.

There are other key challenges, both macro and micro which need policymakers attention like uncertain stakeholder roles, tokenization of energy or blockchain platform, prosumer licenses, balancing obligations, grid interconnection codes, network consignment fees, the smart meter measurement act, privacy protection and centralized decision making. These can be addressed by the implementation of dedicated policy and regulations for the adoption of new technologies. Therefore, the global scaling of the technology will require countries to lay out the framework for institutions to innovate and accelerate blockchain technology and its adoption.

Integration

Another key challenge is the integration of blockchain with existing technology. Until now, market participants have been using systems such as exchange platforms to trade energy, which are already advanced and meet the needs of participants. Migrating the current advanced systems in energy trading to blockchain may not be economically viable even if the technology and scalability supports the migration. Therefore, legacy systems cannot be replaced overnight with blockchain based applications, however blockchain may become a component of the existing system and may gradually replace entire systems in the longer term or continue to function alongside current systems. Therefore, standards for blockchain architectures need to be developed to allow interoperability between different technology solutions. Companies need to conduct thorough due diligence assessment on how the technology can be first integrated with their existing systems before committing huge investment to develop new blockchain based applications.

CONCLUSION

The use of blockchain in energy sector promises to reduce costs, improved process efficiency, and wider participation in trade processes. These models also aim to strengthen the role of prosumers and optimize generation capacity, which eventually can immensely benefit the entire energy ecosystem. The technology can enable and power the sharing economy. It cannot be denied that the solution to manage micro grids and distributed energy resources (DERs) through blockchain technology is promising, however, for wide spread deployment, the technology will have to prove its economic value addition to existing solutions.

Additionally, blockchain use cases have the potential to build an entire ecosystem needed to facilitate and accelerate energy transition to ultimately achieve zero carbon emissions.

As per the result of a survey of executives conducted by Deloitte in 2019, 53% (+10% Y-o-Y) of respondents said that blockchain technology has become a critical priority for their organization. Also 83% (+9% Y-o-Y) see compelling use cases of blockchain[30]. This is a clear indication that the technology is seen as a catalyst for next generation solutions in different industries, including the energy sector.

For the energy sector, by promoting and developing decentralization and digitalization, the blockchain technology has the potential to accelerate grid decarbonization, and meet ambitious decarbonization targets. Therefore, blockchain digitization will be a tool towards the

ultimate goal of achieving rapid energy transition to a 100% renewable energy world[31].

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(2) Ahl, A., Yarime, M., Tanaka, K. and Sagawa, D. (2019). Review of blockchain-based distributed energy: Implications for institutional development

(3) Ahl, A., Yarime, M., Goto, M., Chopra, S., Kumar, N., Tanaka, K. and Sagawa, D. (2019). Exploring blockchain for the energy transition: Opportunities and challenges based on a case study in Japan

(4) Abrishambaf, O., Lezama, F., Faria, P. and Vale, Z. (2019). Towards transactive energy systems: An analysis on current trends

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[1] *Listed on Coinmarketcap at the time of writing.*

[2] *Any computer or device that connects to the blockchain interface may be considered as a node in the sense that they communicate with each other and transmit information about transactions and blocks within the distributed network of computers by using p-2-p protocol(in case of bitcoin).*

[3] *In proof of work (PoW) based public blockchains (e.g. Bitcoin and the current implementation of Ethereum), the algorithm rewards participants who solve cryptographic puzzles in order to validate transactions and create new blocks (i.e. mining). In PoS-based public blockchains (e.g. Ethereum's upcoming Casper implementation), a set of validators take turns proposing and voting on the next block, and the weight of each validator's vote depends on the size of its deposit (i.e. stake). (via Github)*

[4] *https://www.irena.org/newsroom/pressreleases/2019/Apr/Renewable-Energy-Now-Accounts-for-a-Third-of-Global-Power-Capacity*

[5] *https://www.ofgem.gov.uk/gas/retail-market/metering/transition-smart-meters*

[6] *Once a transaction is recorded, it cannot be altered.*

[7] *IFPEN internal study of August 2019.*

[8] *Based on granular assessment of Fig. 3 by Mckinsey.*

[9] *Based on a presentation from OutlierVentures.*

[10] *Supranote 7*

[11] *Based on 215 identified projects by IFPEN*

[12] *Related to power and gas trading*

[13] *https://www.ponton.de/enerchain-1-0-is-live/*

[14] *https://www.sunchain.fr/en#team*

[15] *https://www.powerledger.io/our-technology/*

[16] *Supranote 7*

[17] *Supranote 11*

[18] *(PoA) is an algorithm used with blockchains that delivers comparatively fast transactions through a consensus mechanism based on identity as a stake.*

[19] *PoW mechanism is energy intensive*

[20] *Supranote 7*

[21] *Supranote 11*

[22] *Stablecoins are cryptocurrencies designed to minimize the volatility of the price of the stablecoin, relative to some "stable" asset like USD/Euro or basket of assets. A stablecoin can be pegged to a cryptocurrency, fiat money, or to exchange-traded commodities (such as precious metals or industrial metals).*

[23] *Check 5*

[24] *Supranote 11*

[25] *https://www.usine-digitale.fr/article/blockchain-engie-et-ledger-inventent-un-boitier-pour-authentifier-les-donnees-en-entree.N767439*

[26] *Radical change to a network protocol that makes previously invalid blocks or transactions valid or vice versa.*

[27] *https://digiconomist.net/bitcoin-energy-consumption*

[28] *Byzantine Fault Tolerance(BFT) is the feature of a distributed network to reach consensus(agreement on the same value) even when some of the nodes in the network fail to respond or respond with incorrect information. The objective of a BFT mechanism is to safeguard*

against the system failures by employing collective decision making(both – correct and faulty nodes) which aims to reduce to influence of the faulty nodes. BFT is derived from Byzantine Generals' Problem. (via https://www.geeksforgeeks.org/practical-byzantine-fault-tolerancepbft/)

[29] https://ec.europa.eu/digital-single-market/en/blockchain-technologies

[30] https://www2.deloitte.com/content/dam/Deloitte/se/Documents/risk/DI_2019-global-blockchain-survey.pdf

[31] https://fsr.eui.eu/wp-content/uploads/Blockchain_meets_Energy_-_ENG.pdf

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